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"THE ROCKCLIFFE ICE WAGON" AND ITS ROLE IN CANADIAN ICING RESEARCH

SUMMARY

A brief description of the icing research North Star aircraft known as "The Rockcliffe Ice Wagon" is given. The principles and recent trends of electro-thermal propeller and wing de-icing are outlined.

The nephelometric instrumentation of the aircraft is described, and a preliminary analysis is presented of measurements of liquid water contents and temperatures of supercooled clouds encountered during 1950 and 1951 icing research flights.

The need for statistical data on which to base meteorological design criteria for aircraft icing protection is stressed and plans to fit simple liquid water content instruments to airline aircraft are described.

INTRODUCTION

All aircraft operating in temperate to arctic climates encounter the hazards of icing. In Canada, icing conditions may occur over large areas during the entire year and over the majority of airlanes for ten months of the year. Trans-Canada Airlines report 5% of their total flying time is spent in icing conditions even though flights are planned to avoid them. On the North Atlantic route, McTaggart-Cowan (ref. 1) reports that the probability of encountering icing conditions, at altitudes below 15,000 feet, is 100% from September to May.

Present-day knowledge allows the complete protection of an aircraft against ice but economy of design is still a necessity. An accurate knowledge of the physics of clouds is, therefore, essential to further progress in the field of aircraft icing research. Such knowledge could aid in the forecasting of icing conditions; would provide exact design conditions for more effective and economical protection; and would make possible better simulation of icing conditions in the laboratory.

The majority of icing research in Canada has been the direct responsibility of the National Research Council and is now continuing under the National Aeronautical Establishment. All flight facilities are provided by the Royal Canadian Air Force. For the past five years, I have been seconded to the Low Temperature Laboratory of the National Research Council and have been actively engaged in their de-icing and cloud physics projects. This paper proposes to discuss these projects generally, and in particular, to present some of the results obtained from the icing research North Star aircraft known as "The Rockcliffe Ice Wagon".

AIRCRAFT DE-ICING PROJECT

HISTORICAL REVIEW

Aircraft icing research is still a comparatively new field since the problem was not recognized until instrument flights on a large scale began in the late 1920's. Work in the National Research Laboratories began about 1935, and early in the research programme it was decided that thermal methods offered the best means of protection. A further decision was made to concentrate, initially, upon propeller de-icing since maintenance of thrust was considered the prime requisite.

It has been a principle of the Laboratories that as much development work as possible and all final testing of de-icing equipment should be conducted in flight under conditions of natural icing. To this end, flight tests of de-icing equipment began in 1942 and the North Star aircraft now in service is the successor of a series of aircraft which have been employed since that date.

"THE ROCKCLIFFE ICE WAGON"

The present research aircraft is a well-equipped flying laboratory. Basically the aircraft is a Canadair GMI North Star. The most prominent external feature is a large dorsal fin mounted midship. This fin is a symmetrical section having a 10-foot chord and a span or vertical height of 8 feet. It embodies a leading edge which is removable in toto to 20% chord to facilitate mounting of experimental wing heater elements. Ahead of the fin and slightly to each side are two blisters from which observations of fin icing experiments are easily made.

The four propellers are equipped with N.R.C. conducting rubber heater elements and a special plane glass window has been installed ahead of the port propellers to observe propeller icing.

Electric power for the propeller and fin heater elements is provided by engine-driven, 400-cycle, 3-phase, 208-volt alternators mounted one in each outboard engine. These alternators are capable of supplying 60 KVA each at a weight-power ratio slightly in excess of 2 lbs. per kilowatt. Fortunately the gear boxes were designed to handle the pressurization cabin blowers and no engine modifications were necessary to instal the alternators. The ability of electro-thermal de-icing to meet competitively the weights of other de-icing systems is dependent upon the low weight-power ratio of this type of alternator.

Within the aircraft a main power station houses the primary controls and safety equipment associated with the alternators. The propellers are fed from the port alternator through a control-observation station located on the port side ahead of the propellers. The fin is supplied by the starboard alternator and the controls are located at the port blister. An emergency transfer system is incorporated in the power station so that both loads may be supplied by either alternator in case of engine or alternator failure.

The main meteorological instrument panel is located on the port side of the aircraft immediately aft of the propeller observer station. Due to the number and complexity of the meteorological instruments, an instrument engineer at this position makes primary adjustments and aids in the operation of the instruments. The meteorological observer is located in the starboard blister where a clear view may be obtained of sky and cloud conditions. Duplicate operating controls of all meteorological instruments are located at this position together with a number of special instruments.

The four scientific positions are connected by intercommunication separate from the aircraft system and each position is provided with a wire recorder.

A flight crew of five normally operates the aircraft. In addition a complete ground crew and a stock of small spares are carried. Thus the aircraft and crew are a self-contained unit which can operate away from base for extended periods of time.

PROPELLER DE-ICING

Modern methods of propeller protection depend in general upon a de-icing system (ref. 2), whereby the ice is shed periodically rather than an anti-icing system where the propeller is completely protected against ice formation. De-icing is achieved by heating the propeller blade to form a water interface between the ice and the blade so that centrifugal force can effect the removal of the ice cap. This method of propeller protection employing rubber heater elements is the direct development of the propeller icing research initiated in 1939 at the National Research Laboratories.

The North Star propeller heater elements are designed to N.R.C. specifications. They consist of a conducting rubber layer embedded between a thick heat-insulating base layer and a thin outer protective layer of non-conducting rubber. Normally, a heat concentration is provided at the leading edge of the order of twice the aft sections to expedite the shedding of rime ice formations. The coverage is considerably greater than commercial installations, extending to 35% chord and to within 12 to 18 inches of the blade tip. Provision is made to vary the heat concentration from half power to a full power wattage of about 3,000 watts per blade, providing a leading edge power concentration of 15 watts/in^2. at the latter power.

During initial experiments the propeller blades were heated continuously at a sufficiently low power concentration so that ice could form. The thermal insulation provided by the ice cap allowed the formation of a water interface and shedding occurred. Modern practice now cycles the power to the heater element intermittently thereby achieving a power saving during ice build-up. Further, this method minimizes the amount of run-back on the blade due to afterfreezing of the melted ice.

Although definite design criteria have not been established, experiments on the North Star propellers show a power savings by increasing the specific power concentration of the heater element and thereby effecting shedding in a shorter time. Shedding times of approximately 2 seconds have been obtained at $-10^{\circ}C$. with leading edge power concentrations of 11 watts per in^2.

WING DE-ICING

The successful development of electro-thermal propeller icing protection led to the application of this method to stationary aerofoils. The principles of the method were established during flight tests of the RY-3 Privateer icing research aircraft (ref. 3), the predecessor of the present North Star. Since ice removal is effected here by aerodynamic forces rather than centrifugal force the ice cap must be parted at the aerofoil leading edge to prevent the formation of a stable ice cap.

The dorsal fin of the North Star has provided an aerofoil on which refinements of the method and design criteria have been established. Two heater elements are mounted on the leading edge of the fin to provide direct comparison of either differing designs or differing power concentrations. The present heater elements consist of woven wire embedded in rubber and consist of a leading edge parting strip and front and rear shedding zones. Dividing strips are used to prevent ice anchorage from one heater element to the other or from the heater elements to the unprotected wing surface. In general, the ice accumulates on the front shedding zone and is shed from it periodically by the application of heat to form a water interface. The rear shedding zones are provided in case of severe afterfreezing such as might be encountered under freezing rain conditions.

Since it is impossible to provide the necessary electric power for complete anti-icing or even simultaneous de-icing of all aerofoil surfaces, shedding is effected by cycling power to each shedding zone in turn. A maximum cycle rate of 20 seconds heating period to 160 seconds cold is indicated under heavy icing conditions.

As with the propellers, energy savings are accomplished by a high specific power concentration on the shedding zones and values as high as 15 watts per square inch may be necessary. The total energy requirement of an electro-thermal wing de-icing system is estimated at about 1/10 that of a hot gas anti-icing system.

The shedding time is dependent upon the ambient air temperature increasing with decreasing temperature. Leading edge power concentrations also affect the shedding time and an automatic control which will just maintain the parting strip clear is envisaged.

CLOUD PHYSICS PROJECT

The establishment of a cloud physics project in conjunction with icing research was a natural development. The icing project was vitally interested in the conditions under which its tests were conducted and there was a need for design criteria and data for icing tunnel simulation. Therefore in 1945 the Meteorological Division seconded a meteorologist to the project and the design of suitable nephelometric instruments was initiated (ref. 4).

PARAMETERS

Before proceeding further with this discussion an examination of the parameters involved would be of value. Of basic interest to the meteorologist are temperature, altitude, extent and severity of the icing condition. In conjunction with these variables the designer of icing protection requires quantitative data of liquid water content, cloud droplet size and droplet size distribution. There are, in addition, a number of other properties such as composition, distribution and electrical charge of the cloud particles which are of interest to the cloud physicist.

The overall range of magnitude of these parameters is so great that only a statistical survey will be of real value. Liquid water concentrations can vary from a few hundredths of a gram per cubic metre to as much as 10 g/m^3 although the latter concentrations are probably of such limited extent as to be unimportant as a design figure. Droplet size extends from a few microns in cloud to several hundred microns in drizzle to a few thousand microns in rain. If we could say definitely that the possibility of encountering freezing rain or drizzle were less than one in a hundred or even one in a thousand, would the designer cater for such extreme conditions? Icing has been reported infrequently at temperatures as low as -40°C. Is the penalty for protection at this low temperature greater than the risk of such an encounter?

Economy and efficiency of design require a solution of these questions. The problem presented in the nephelometric instrumentation of the North Star is therefore the enlarging of our general knowledge of cloud physics and the necessity for the development of instruments that can be widely fitted to scheduled aircraft for a statistical investigation of cloud properties.

The design of such meteorological instruments is exacting. They must be capable of delicate measurements, yet sufficiently robust for use in an aircraft. They frequently require to be mounted at a distance from the aircraft in order to approximate free air conditions. In this case, they must also permit efficient de-icing without affecting the measured parameter. Finally, they must be capable of obtaining accurate measurements at flight speeds. The development and perfecting of such instruments is difficult and time consuming.

The parameters and their range of magnitude of probable interest in icing research are tabulated below together with the instruments for measuring these parameters.

TABLE 1

Parameter	Probable Range	Instrument
Liquid water content	.05 to 7.5 g/m^3	Rotating Disc Rate of Icing Meter
		Rotating Cylinders
		Orifice Type Icing Meter
		"Hot Rod"
		#Cloud Density Meter
Cloud droplet size	2 to 5000 microns	Cloud Droplet Camera
		Oiled Slide
		Rotating Cylinders
		#Cloud Density Meter
Temperature	-50 to 10°C.	Non Wetting Thermometer Housing
		Vortex Tube Thermometer

The Cloud Density Meter obtains the ratio of Liquid Water Content to Average Cloud Droplet Size.

MEASUREMENT OF LIQUID WATER CONTENT

Probably the most important single cloud parameter is the liquid or free water content, upon which the rate of accretion of ice is largely dependent.

The primary method of determination of liquid water content is the measurement of the amount of ice collected by an impactor exposed to the supercooled water droplets over a known length of air path. This is convertible to liquid water content if the collection efficiency of the impactor is known. This collection efficiency increases directly with water droplet size and inversely with impactor scale. Examples of this method are the rotating disc and rotating cylinders.

Rotating Disc Rate of Icing Meter

The rotating disc type of instrument (ref. 5) is based on the premise that a small cross-section impactor approaches 100 per cent collection efficiency and to a first approximation is independent of droplet size.

In the N.R.C. version a 1/16 in. thick by 2-1/8 in. diameter disc, rotating at 2 r.p.m. is presented edge on to the airstream. Any point on the edge of the disc collects ice during approximately two thirds of the interval that it is forward facing into the airstream. This in effect averages the rate of accumulation over a 10-second period.

A feeler located at the rear of the disc continuously indicates the thickness of the ice accretion which is then removed by a spring loaded scraper. Both visual readings and a continuous photographic trace are provided by a magnesyn transmitter geared to the feeler.

This instrument may be regarded as one of the most important meteorological instruments installed in the aircraft. The rate of accretion is convertible into reliable liquid water contents. The photographic recording is invaluable for the comparison of different icing conditions. Further, since this instrument is compact, can be made comparatively rugged and the data are capable of easy analysis, it offers promise for an instrument which may be fitted on airline aircraft for the collection of statistical data.

Rotating Cylinder Apparatus

The paths of moving water droplets in the vicinity of cylinders have been studied by M. Glauert (ref. 6) who assumed that Stokes Law applies and later by Langmuir and Blodgett (ref. 7) who modified the theory to include larger droplets and the high accelerations experienced at flight velocities when Stokes Law is no longer valid. Standard theoretical curves have been prepared by which the collection efficiency of a given size cylinder may be determined as a function of droplet diameter, droplet size distribution, and velocity of the droplet.

The rotating cylinder apparatus exposes simultaneously a number of cylinders of different diameters over a known length of air path. The cylinders are rotated to ensure a uniform coating of ice. Since the cylinders have different collection efficiencies, different amounts of ice are collected from which a curve may be constructed against cylinder diameter. This curve is fitted to the standard curves and in effect extrapolated to zero diameter or 100 per cent efficiency from which condition the liquid water content may be calculated. The shape of the curve allows the determination of average droplet diameter in addition to the droplet size distribution.

The instrument suffers from a number of disadvantages (ref. 8). It is awkward to operate and requires considerable finesse in determination of the amount of ice. The results are obtained intermittently and are averaged over a considerable period of time. The calculations are laborious. The droplet diameter and droplet distribution values are subject to considerable inaccuracy. Under conditions of high water content and high temperature blow-off of water may occur.

Because of these practical disadvantages the instrument is not in use on the North Star and is only mentioned here since it has heretofor been used as a standard elsewhere.

Orifice Type Icing Meter

This instrument (ref. 9) consists of a tube with a number of small forward-facing positive pressure holes. The positive pressure is nearly balanced by a smaller number of rearward-facing holes. Under icing conditions the forward holes block and a switch is actuated by the pressure change. An internal electric heater de-ices the tube and the cycle repeats. At constant airspeed the icing time is inversely proportional to the liquid water content.

Since such an instrument is light and compact and can be made to indicate an ice accretion of about 25 thousandths of an inch, its use is planned for statistical measurements. The instrument is easily adapted to recording. It can be used with an electronic rate meter or a simple count of total cycles can be made.

"Hot Rod"

The "hot rod" is a tube approximately 9 inches in length and $\frac{1}{4}$ inch in diameter fitted at the outer end with a scale. The rod is mounted in such a position in the airstream that any ice accretion is easily visible. A manually-operated internal heater permits de-icing. The time to accumulate a standard thickness of ice is a measure of the severity of icing and permits a calculation of the liquid water content. It is hoped that a number of these will be installed in the near future on airline aircraft to provide statistical data of liquid water content and icing severity. It has been suggested that such data could be entered on the flight cross-sections prepared by airline pilots.

CLOUD DROPLET SIZE AND DROPLET SIZE DISTRIBUTION

The measurement of these parameters in flight is an exacting problem. The results are of interest to the designer of de-icing equipment in planning extent of protection. The use of rotating cylinders mentioned above offers one method of attack although the accuracy of the results are in doubt. Two other methods employed at present on the North Star aircraft show considerable promise. These are the Cloud Droplet Camera and the Oiled Slide technique.

Cloud Droplet Camera

A camera capable of photographing cloud particles has been under development in the laboratories for a number of years (ref. 10). Two models have been constructed, of which the second improved type (ref. 11) is now in use on the North Star and has successfully photographed cloud particles.

The cloud droplet camera depends upon the shadowgraph method of photography whereby the object to be photographed is situated between the light source and the camera lens. The object then appears on the developed film as a light image against a dark background.

To adapt this method to the photography of cloud droplets in flight, compensation of the movement of the aircraft must be effected. This is accomplished by:

(1) A high intensity short duration spark gap discharge as a source of illumination.
(2) The use of rotating prisms between the objective lens and the film in order to "stop" the droplet and to obtain a true image rather than an image elongated in the direction of flight. A stationary image on the film is obtained by adjusting the angular velocity of the prisms to the true speed of the droplet relative to the camera. The present camera design employs two prisms rotating at different speeds thus allowing light to pass through both of them only once during a number of revolutions. No shutter is therefore necessary. When the prisms are synchronized with the true air speed, coincidence of the prisms allowing an exposure every 197 feet is obtained with the present gear ratio. Completion of the electrical circuit and breakdown of the spark gap are arranged to occur only at coincidence of the prisms. The film moves continuously through the magazine at a rate sufficient to eliminate overlapping of the exposures.

A 6.88 magnification of the droplet is provided by the optical system, since otherwise the image of small droplets approaches the grain size of the film.

The use of a camera to obtain cloud droplet size and size distribution data has obvious advantages. The droplets are undisturbed in their motion. The operation of the camera is convenient and a large number of individual samples can be obtained in a short period and recorded permanently. A serious disadvantage is the small focal volume and the necessity for a large number of photographs for statistical analysis. Moreover the analysis of the results is extremely slow and tedious.

Notwithstanding, with further improvements now in hand, the cloud droplet camera may become a standard.

Oiled Slide

A technique of catching droplets on an oiled slide has been developed in the Engine Laboratory (ref. 12) of the National Research Council. Similar methods employing slides coated with heated vasoline, soot and hydrophobic compounds have been used previously but the droplets were broken, flattened or absorbed and corrections to the observed diameters were necessary. The particular oil used in this technique has a viscosity such that the droplets apparently are decelerated gently and retain their original form. An oiled slide is exposed briefly to the airstream by means of a tubular holder. This method appears to obtain a representative sample before the air flow can adjust itself to the obstruction and centrifuging of the small droplets can occur. In an average exposure, several hundred droplets are caught and these are photographed through a twenty power microscope. Further enlargement to a total magnification of 100 is obtained in printing of the negative. Measurement of droplet size is made directly from the photographic print. A high standard in the developing, enlarging and printing technique is required. The method shows promise for a statistical analysis of drop size and drop size distribution since a large number of droplets can be obtained in each sampling. As with the droplet camera the analysis of the data is lengthy.

Comparison of Oiled Slide and Droplet Camera Techniques

The droplet camera permits photographing of cloud particles in their environment. A comparison of the results is therefore of interest in assessing their degree of accuracy. Comparisons both of natural droplets in flight and simulated droplets in the icing wind tunnel are in progress. Preliminary analysis indicates a remarkable degree of agreement, particularly in the determination of average droplet diameter. The oiled slide technique shows a higher number of small droplets which although they do not seriously affect the average diameter, cause a considerable variation in the distribution curves.

The cloud droplet camera is capable of photographing either liquid or ice crystal cloud particles. To date, the oiled slide technique has been applicable only to liquid cloud droplets.

CLOUD DENSITY METER

The percentage extinction of a constant intensity light source projected through a known path length of cloud gives a quantity which is related to the ratio W/D_a where W is the liquid water content and D_a is the average diameter of the cloud droplets (ref. 13 and 14). Although neither of these quantities is directly measured by the instrument, if the value of one is known the other can be immediately derived. Moreover the ratio is of use in checking the more fundamental measurements of the other instruments described heretofore.

Measurement of the light extinction is made by means of a photocell. Settings of 100 per cent and 0 per cent transmission are made manually and intermediate percentages depend upon the linearity of the electronic amplifiers of the instrument.

The effect of natural illumination is overcome by the use of a 1200-cycle light source and the selective filtering of this frequency by the amplifier.

A sufficiently long path through the cloud is obtained by means of an outrigger and folding of the light beam.

A number of difficulties, both mechanical and electrical, have been encountered to date in the operation of this instrument. Considerable full scale testing in the large icing tunnel is anticipated before the difficulties are solved and an instrument capable of giving reliable results is achieved.

THERMOMETRY

Considerable effort has been devoted to an increase in the accuracy of air temperature measurement in flight.

A moving thermometer experiences an aerodynamic heat rise (ref. 15). In dry air, calibration of the individual thermometer in situ allows this temperature rise to be determined with a fair degree of accuracy. In cloud, above freezing, a correction for evaporative heat loss is possible if the thermometer element is completely wetted (ref. 16). If however, the thermometer element is only partially wetted or if the thermometer element becomes coated with ice the exact extent of the evaporative cooling correction is in doubt.

Non-Wetting Thermometer Housing

A thermometer which is adequately shielded to prevent icing of the element usually has only a small and uncertain air flow over the element, thus inducing a large lag in the temperature response.

A design has been evolved whereby adequate ventilation of the thermometer element is achieved from the rear of the housing after separation of the water droplets. Preliminary observations in flight have shown the instrument readings to be unaffected by cloud. An extensive calibration of the instrument both in dry and wet air must yet be undertaken before temperature measurements can be considered reliable.

Vortex Tube Thermometer

The Hilsch effect, by which air is admitted tangentially to a tube so as to form a vortex, causes a reduction of temperature at the centre of the tube (ref. 17). It is believed that this temperature reduction may be adjusted to exactly counteract that due to aerodynamic heating (ref. 18). In effect, a thermometer is created which has no kinetic temperature correction.

Study of a thermometer of this type is in progress in the Laboratory. Preliminary indications that the thermometer element is wetted have been obtained and combining of the Hilsch effect with a thermometer housing of the non-wetting type may be necessary.

Thermometer Elements

A number of thermometer elements of different designs are in use at present on the North Star and none is entirely satisfactory. The British Meteorological Office flat plate platinum resistance thermometer suffers from the disadvantages of its comparatively large size and need for manual balancing. Nor can it be readily converted into a recording instrument. A thermopile in use in the non-wetting housing is considerably more compact and is a direct reading instrument. However, it requires an ice-water cold junction and the low driving power available requires mounting of a sensitive indicator close to the thermometer element. This latter requirement makes its use as a recording instrument difficult.

An accurate, compact, low lag thermometer element employing a thermistor and unbalanced bridge circuit is under development. The use of a sturdy direct reading meter and ease of recording are possible. However, the need for a high standard of electronic voltage stabilization will make the thermometer of use only as a research instrument.

FLIGHT RECORDER

Continuous records of air temperature, indicated air-speed and altitude are obtained as photographic traces on a moving film. In addition, the rotating disc rate of icing and a base time marker are recorded. Two film speeds are available, the higher speed providing a more detailed record. The results of such an instrument are extremely valuable both as a record of flight and icing conditions, and as an aid in evaluating data of the other instruments discussed previously.

RESULTS TO DATE

Although the results to date are not as extensive as desired, a certain success has been achieved and a beginning made on the problem of nephelometric measurements.

With the small staff available and the necessity for continued instrument development it has been inevitable that a back log of data should occur. Thus the measurement and analysis of a number of cloud droplet films is still largely untouched.

Use of an improved droplet camera spark source during a recent flight resulted in pictures of a high quality showing ice crystals, snow flakes and liquid water droplets both separately and in co-existence. Design of a special projector for cloud droplet analysis is now proceeding and droplet distribution measurements will be available shortly.

Preliminary analysis of temperature and liquid water concentrations, obtained from rotating disc measurements, during the last two years is now progressing. Complete analysis of this data and the final form of presentation are still pending.

It should be noted that the majority of the measurements were made during late spring icing flights and the curves will not therefore be typical of all-season operations.

Fig. 1 presents an ogive of percentage occurrence of icing instances versus average liquid water content. 95% of the icing occurred in clouds having water concentrations less than .6 g/m^3, and the highest average measured was of the order of .9 g/m^3.

The percentage occurrence of icing instances versus maximum or peak liquid water content is shown in Fig. 2. In 95% of the instances peak values below 0.9 g/m^3 were measured. The highest maximum water content measured was 1.5 g/m^3. This occurred on the 24th of June of this year east of Winnipeg at a height of 10,500 feet and an ambient air temperature of -3.5°C., in the top of a broken Cumulus layer. The average water content associated with this instance was .6 g/m^3.

Figure 3 presents an ogive of percentage icing occurrences versus temperature, 95% of the cases occurring above -16°C.

Limiting lines of both maximum and average liquid water content versus ambient air temperature are shown in Fig. 4 for 1950 and 1951 North Star icing flight tests. The trend towards lower liquid water concentrations with decreasing temperature is well marked.

FUTURE DEVELOPMENTS

The need for design criteria for the protection of aircraft against ice has been stressed heretofore. This problem is now being attacked on an international basis and ICAO is preparing a Meteorological Recommendation for the Classification of Air Frame Icing and Data Collection. Frankly, we consider the proposed classification recommendation too complex in its present form and are now engaged in a study of all available icing data with the view to submitting a simpler, more fundamental classification. The urgent need at present is for liquid water content and air temperature data, cloud droplet size and altitude appearing to be of secondary importance.

The need for statistical measurement of liquid water content can be met immediately by the use of the orifice type icing meter or alternately the hot rod. Plans to fit these instruments to a number of Canadian airline aircraft are proceeding at present.

In addition to these instruments which will provide instantaneous indications of water content, five compact recorders are being obtained to be placed in service on continental and North Atlantic routes. These will record liquid water content, air temperature, indicated air speed, altitude and G.M.T. time (ref. 19).

Future progress of icing research is now dependent upon the collection of icing statistical data and the establishment of acceptable meteorological design conditions. This is a field in which Canadian research can and should make a significant contribution.

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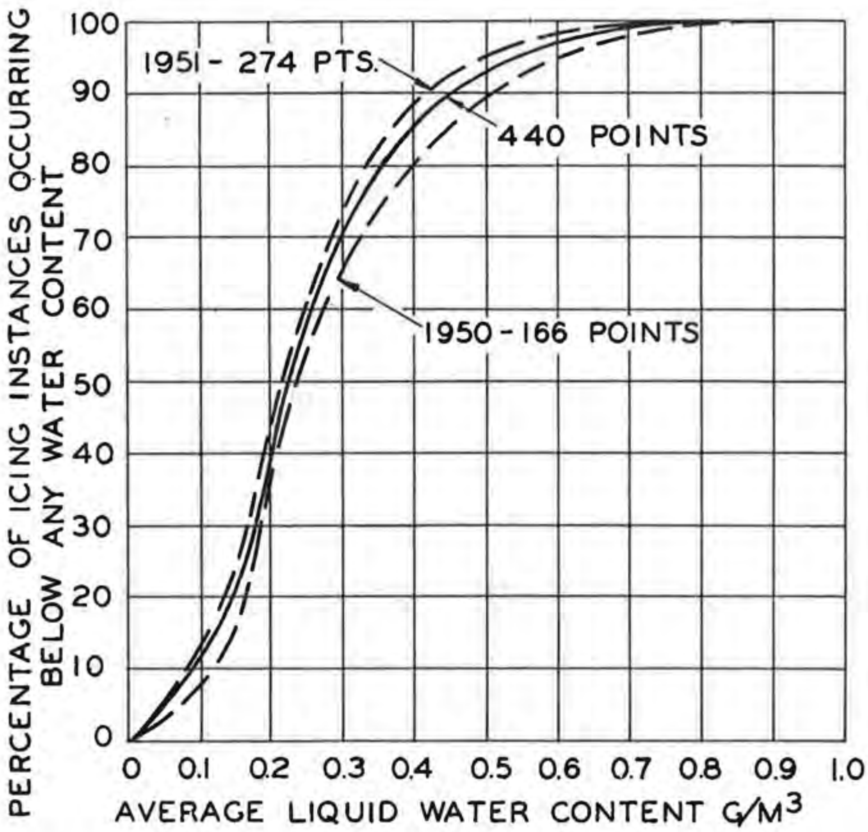
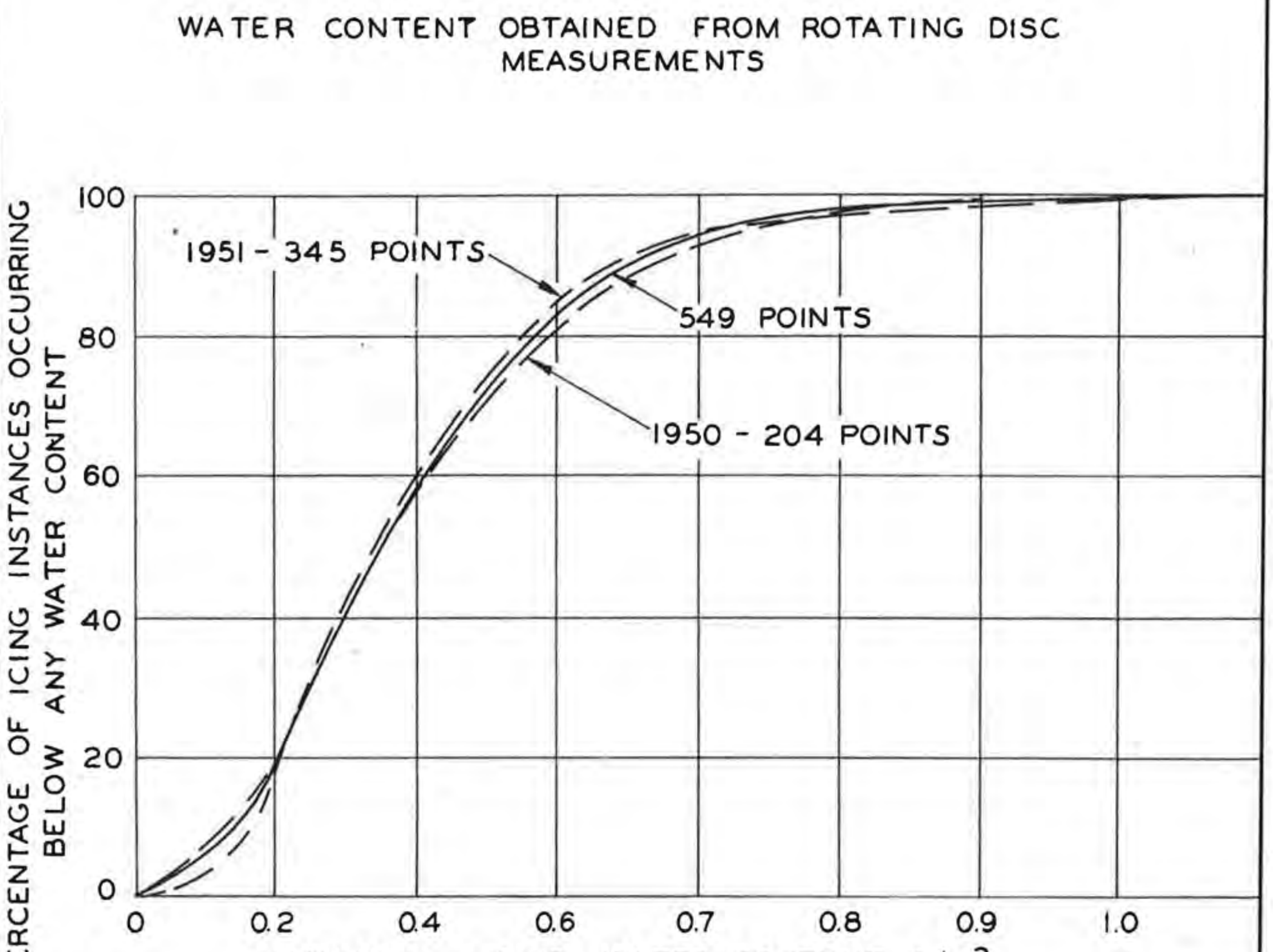
FIG. 1

WATER CONTENT OBTAINED FROM ROTATING DISC. MEASUREMENTS



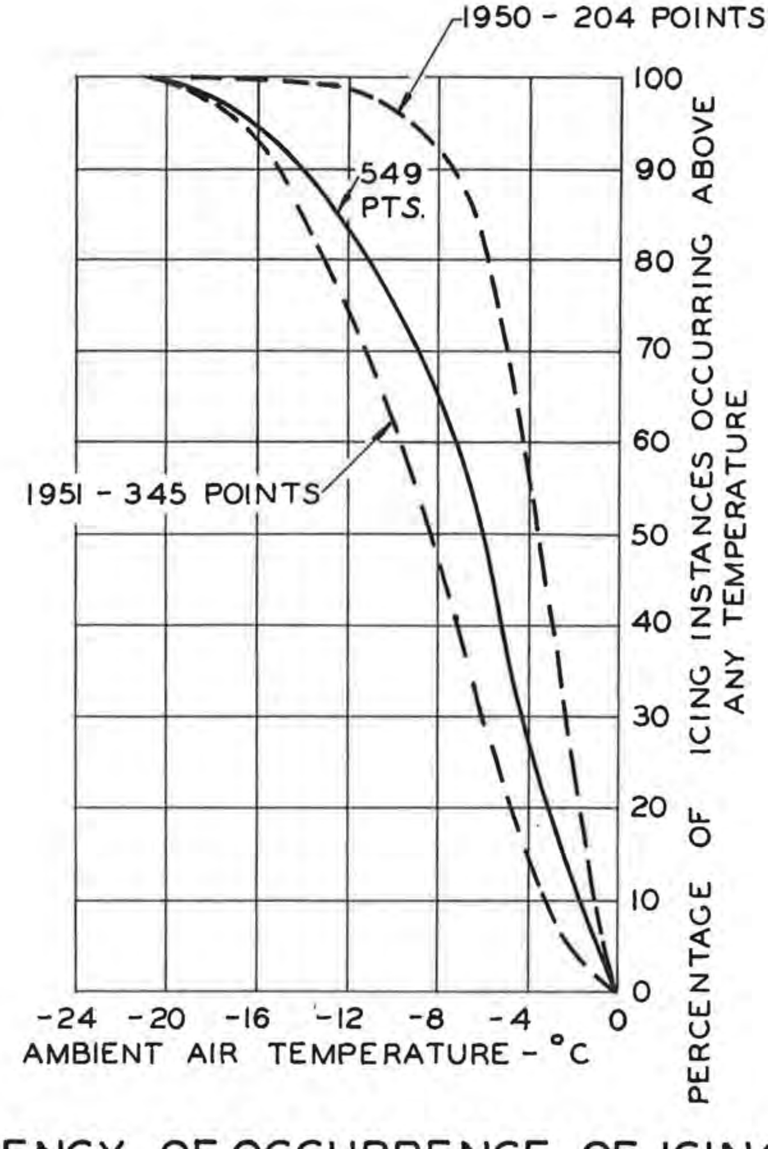
FREQUENCY OF OCCURRENCE OF ICING CONDITIONS BELOW ANY WATER CONTENT

FIG. 2



FREQUENCY OF OCCURRENCE OF ICING CONDITIONS BELOW ANY WATER CONTENT

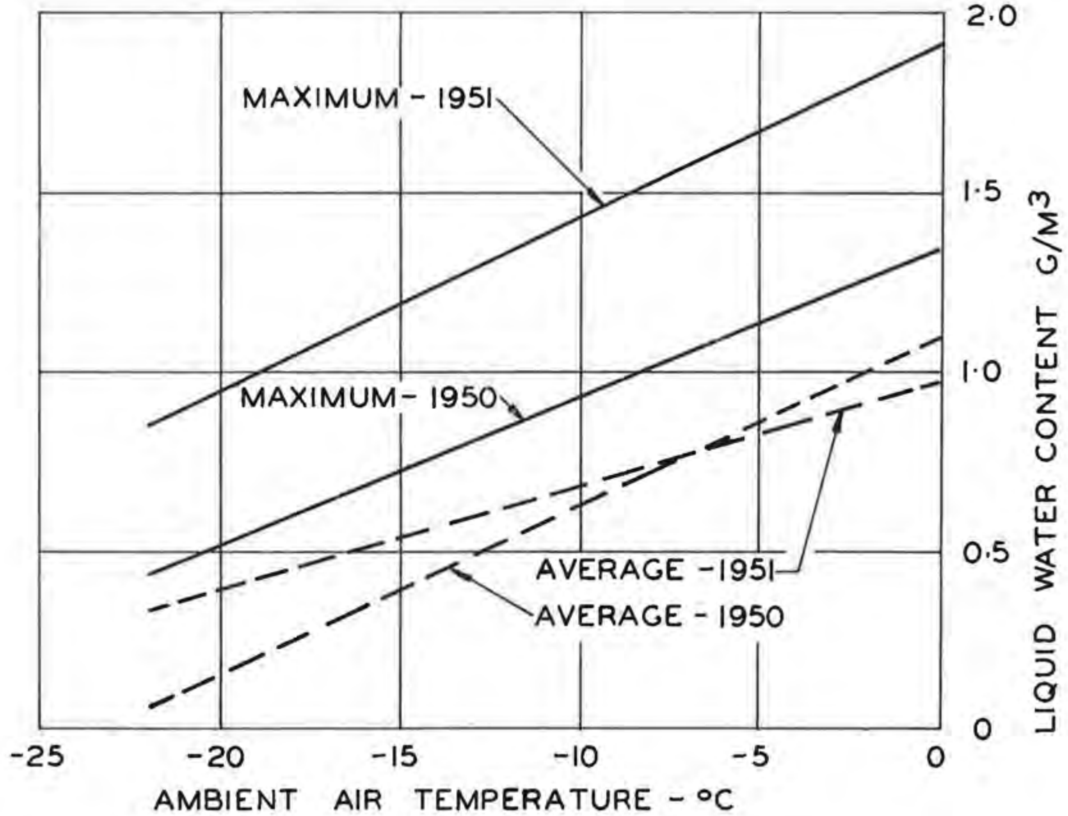
FIG. 3



FREQUENCY OF OCCURRENCE OF ICING CONDITIONS ABOVE ANY TEMPERATURE

FIG. 4

WATER CONTENT OBTAINED FROM ROTATING DISC MEASUREMENTS



LIMITING LINES OF LIQUID WATER CONTENT VERSUS TEMPERATURE OBTAINED DURING 1950 & 1951 NORTH STAR ICING FLIGHTS