NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3984

STATISTICAL STUDY OF AIRCRAFT ICING PROBABILITIES AT THE 700- AND 500-MILLIBAR LEVELS OVER OCEAN AREAS IN THE NORTHERN HEMISPHERE

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SUMMARY

A statistical study is made of icing data reported from weather reconnaissance aircraft flown by Air Weather Service (USAF). The weather missions studied were flown at fixed flight levels of 500 millibars (18,000 ft) and 700 millibars (10,000 ft) over wide areas of the Pacific, Atlantic, and Arctic Oceans. This report is presented as part of a program conducted by the NACA to obtain extensive icing statistics relevant to aircraft design and operation.

The thousands of in-flight observations recorded over a 2- to 4-year period provide reliable statistics on icing encounters for the specific areas, altitudes, and seasons included in the data. The relative frequencies of icing occurrence are presented, together with the estimated icing probabilities and the relation of these probabilities to the frequencies of flight in clouds and cloud temperatures.

The results show that aircraft operators can expect icing probabilities to vary widely throughout the year from near zero in the cold Arctic areas in winter up to 7 percent in areas where greater cloudiness and warmer temperatures prevail. The data also reveal a general tendency of colder cloud temperatures to reduce the probability of icing in equally cloudy conditions.

INTRODUCTION

Knowledge of the frequency of icing conditions during routine or specialized aircraft operations is required for any basic appraisal of the aircraft-icing problem. The need and degree of icing protection required for a particular aircraft can be better determined by both airline operators and military-operations analysts if the probability of encountering icing has been established for the areas, seasons, and altitudes in which the aircraft is to operate. Previous meteorological studies on icing conditions have not shown how frequently icing can be expected over world-wide areas on a year-round basis. Past data were obtained on flights made primarily to determine the extent and magnitude of meteorological conditions conducive to icing.

As a part of a program conducted by the NACA Lewis laboratory to obtain more extensive icing-cloud data, a study was made of the icing data in thousands of in-flight meteorological reports, in order to determine the relative frequency of encountering icing clouds in as many regions as possible throughout the year. These reports were taken from the weather reconnaissance flights made by Air Weather Service. Appreciation is extended to this branch of the U. S. Air Force for supplying the original data records and also to the Wright Air Development Center (ARDC) for assistance in processing the large quantity of data assembled for this study. The weather reconnaissance flights have accumulated, over the past several years, a vast quantity of meteorological records taken over the Pacific, Atlantic, and Arctic oceans. This large quantity of data, representing many flying hours, was necessary to establish reliable icing statistics because of the generally infrequent occurrence of icing conditions.

This report presents a tabulation and preliminary analysis of the icing probabilities and associated data for several specific areas over the three oceans. The results are separated into the four seasons of the year and are restricted to fixed flight levels of 700 and 500 millibars. Data are also included from flights at 1500 feet, which encountered very little icing because of the predominance of above-freezing temperatures at this level. The probabilities of icing were related to the frequencies of cloud penetrations and to the measured cloud temperatures.

A set of punched cards containing all of the data from the weather reconnaissance reports used in this study is on file at the National Weather Records Center, Ashville, North Carolina.

DESCRIPTION OF WEATHER RECONNAISSANCE FLIGHTS

Geographical Location and Survey Period

The weather reconnaissance flights made by Air Weather Service, using WB-29 aircraft, were along established tracks that were not altered appreciably during the period of survey. These tracks, in the northern hemisphere, are plotted on the map shown in figure 1. The flights originated from Air Force bases in Alaska for the Arctic areas; Japan, Guam, Hawaii, and California for the Pacific areas; and Bermuda, the Azores, and England for the Atlantic areas. Straight-line courses were flown, starting near the Air Force base and returning to the originating base after covering up to 2400 miles for the complete flight. These long flights were made almost entirely over ocean areas. The track designations originally assigned by Air Weather Service are retained in this report.

Information for northern latitudes was obtained from tracks over the Arctic Ocean, Bering Sea, and Atlantic Ocean off the coast of Norway. The "Ptarmigan" track extended out over the Arctic Ocean from the North coast of Alaska almost to the North Pole. The Bering Sea area, including the Aleutian Islands, was covered by the "Loon" track. Flights up the 2° east meridian from England to about latitude 75° were labeled "Falcon" track.

The Pacific Ocean was surveyed by several tracks covering the western, north-central, and eastern areas. The western Pacific was covered by the "Buzzard Delta" track, which extended northeast from Japan to about 50° north latitude; the "Buzzard Kilo" track, which extended over the China Sea and Korea areas west of Japan; and the "Vulture" tracks, which covered areas both north and south of Guam. Flights along the "Petrel" tracks provided data for the north-central Pacific, north of the Hawaiian Islands up to about latitude 40° north. The eastern Pacific area was surveyed by the "Lark" tracks, which extended north and west from the California coast up to about latitude 50° north.

The tracks in the Atlantic Ocean covered a large area, although they were lacking in data for all seasons. The three "Gull" tracks, originating from Bermuda, surveyed large areas northwest, northeast, and south of that base. A number of different tracks called "Eagle" originated in the Azores, and each track was used for a relatively short period of time. The limited quantity of "Eagle" data prevented individual analysis of a particular track; and, therefore, these tracks were combined within an area of 20° of longitude and 15° of latitude and labeled "combined 'Eagle' tracks".

The weather data used in this study were taken generally over a 2-year period from May 1952 to June 1954. The arctic areas included additional data through June 1955. In some areas flights were made only during certain seasons, which prevented full-year statistics from those areas. In general, data over a 2-year period was considered the minimum amount needed to eliminate abnormal weather variations that could occur during a particular season.

Flight Procedure

Flight altitudes. - The flights were made at constant pressure levels of 500 millibars (18,300-ft pressure altitude) and 700 millibars (10,000-ft pressure altitude). Flights were made at 1500 feet above the sea surface to obtain approximate surface measurements. Most flights were made using combinations of these altitudes over the complete track. Usually, a fixed level was maintained for approximately half the flight and was followed by a climb or descent to another level for the remainder of the track. The map of figure 1 shows the portion of each track where the pressure levels were flown. The altitude flown most frequently, considering all the tracks, was the 500-millibar level. The predetermined pressure altitude of each flight was maintained regardless of weather conditions, unless severe turbulence or icing, or areas suspected of severe turbulence or icing (thunderstorms), required a change of altitude or course. Flying at a constant pressure level resulted in changes in true altitude above the sea surface. Variations in the atmospheric-pressure pattern along the track throughout the year resulted in true altitudes ranging between 15,000 and 19,000 feet at the 500-millibar level and between 8000 and 11,000 feet at the 700-millibar level.

Reporting procedures. - The in-flight weather observations were taken at predetermined positions along each track. These reporting positions (plotted as circles on the map of fig. 1) were established at 100-mile intervals, giving between 20 and 24 observations about 1/2 hour apart for each flight. Exceptions to the duration of these flights occurred because of abortive missions or special flights. Usually one flight was made each day along each track, providing daily weather records for every position along the track.

All the weather observations were made by trained personnel using standardized reporting procedures. The observer reported conditions at each position on a coded message form developed by the Air Weather Service and adopted as the internationally approved weather reconnaissance code. Instructions for the use of the code are contained in reference 1. For each observation, the aircraft was considered to be at the center of a vertical cylinder 30 nautical miles in radius, and meteorological conditions were reported as occurring within this cylinder.

Although many weather elements were observed, only a few were applied to this study, namely: the occurrence or nonoccurrence of icing, flight in clouds or clear air, air temperature, pressure level, location, and date of flight. The icing reports gave data on the intensity and type of ice and on the location of the icing area; the code also provided for the reporting of icing when it occurred between reporting positions. The reporting of flight in clouds was divided into four categories, defined as being "on instruments" (1) 25 percent of the time, (2) 50 percent of the time, (3) 75 percent of the time, and (4) all of the time. The measured air temperature was corrected for kinetic heating before being reported in code form.

Icing was usually detected visually on the black surfaces of the wing leading edge and on the forward edges of antennas. Most flights were scheduled for daylight hours, although this was not always possible, particularly in the Arctic regions in winter. A code figure was provided to indicate where observation was impossible because of darkness.

METHOD OF ANALYSIS AND PRESENTATION OF DATA

Use of Punched Cards

The large quantity of information available from the weather reconnaissance flights required the use of machine methods for convenience in handling the data. All items reported by the observers were punched directly on cards in the original coded form. Each position report required the use of two cards to transcribe the large amount of data contained therein; these two cards were later condensed into a single card for each observation. Table I lists the observed data as it was punched in the card columns on the single card. This summary card provides space for recording data relative to two cloud layers. In cases where more than two layers existed, an additional summary card was made, which contained only the identifying information (card columns 1 to 10) and the additional cloud information. The observations that included reports of icing were individually tabulated from the punched cards to provide a convenient form for the detection of inconsistencies in the over-all reports.

The cards were separated into groups for the statistical study, according to area (track), season, and flight level. The seasonal categories were established as follows:

(1) Spring - March, April, May

(2) Summer - June, July, August

(3) Fall - September, October, November

(4) Winter - December, January, February

Table II lists 100 card groups separated according to this procedure, with the corresponding number of observations for each group. The years that were included within each season are also listed. The amount of data in each group varied considerably because of the differences in flight operations among the bases during the periods chosen for the study. Since the data were not broken down by months, data for a particular season and year should not be considered equally distributed throughout the three months included in each season.

Selection and Evaluation of Icing Data

The selection of items for detailed presentation was based on their importance in the study of two aspects of icing climatology: (1) the relation of icing to clouds and temperature and (2) the extent and frequency of icing encounters.

In the study of icing with respect to clouds and temperature, only reports of icing occurring at the time of observation were included, since simultaneous data on temperature and flight conditions were required. All observations in which icing (past or present) was reported were examined individually, and those in which icing occurred at the time of observation were tabulated with the associated temperatures and flight conditions.

In the determination of the extent and frequency of icing encounters, it was necessary to establish the distance from each observation position to the beginning and ending of the icing area. Individual sequences of reports were examined and the total length of each icing encounter was determined, based on the assumption that the distance between reporting positions was 100 nautical miles.

In a number of the icing encounters, the interpretation of the data was complicated by errors and inconsistencies in the coded reports. Rejection of all inconsistent reports obviously would have led to a serious bias in the results. An attempt was made, therefore, to interpret doubtful data so as to introduce a minimum of bias.

RESULTS AND DISCUSSION

Icing in Relation to Clouds and Temperature

Data on free-air temperature, flight in clouds, and icing for each flight track, season, and altitude for which an appreciable number of observations occurred at temperatures below freezing are listed in table III. The data groups in table II with most of their observations above freezing are not included in table III. For each flight level, the following three items were tabulated by 5° C temperature intervals:

(1) Total number of observations N

(2) Number of observations in which the flight was reported to be continuously or intermittently in clouds n

(3) Number of observations in which icing was reported as occurring at the time of observation x

Also included in table III for each 5° temperature range are values for the ratios of in-cloud and icing observations to total observations (n/N and x/N, respectively) and the ratio of icing to in-cloud observations (x/n).

These results are summarized in table IV, which includes also the average temperatures for total observations, cloud observations, and icing observations.

Probability of clouds and icing. - The ratios n/N and x/N are statistical estimates of the probability of flight in clouds or icing conditions, respectively. The icing-to-cloud ratio x/n is a statistical estimate of the conditional probability of icing when clouds are known to be present. For the data groups listed in table IV, the probability of icing varies from zero to nearly 7 percent, with half the values below 2.3 percent. The probability of flight in clouds varies from 1.5 to 28 percent, with a median of 12.8 percent, and the icing-to-cloud ratio varies from zero to 54 percent with a median of 19 percent.

The interpretation of these ratios as estimates of probability is based on the concept of probability as the percentage of successes in a large number of independent trials of a discrete event. In this case, the event is the observation of the occurrence or nonoccurrence of cloud penetration or icing at a particular time. An observation may be regarded as a discrete event when the observation period is short compared with (1) the interval between observations and (2) the usual duration of flight in clouds or icing. Successive observations may be regarded as independent, repeated trials if the distance between them is large compared with the scale of cloud systems on the weather map.

In the instructions to observers (ref. 1), the time of the flight-level observation is defined as the time at which the aircraft is at the center of a cylinder 30 nautical miles in radius; all elements are observed as close to this time as possible. The reporting of icing "at the present position" refers specifically to the "time of the flight-level observation." "Flight condition" (including cloud penetration) is defined as the average during the time required to make the flight-level observation. Thus, both elements appear to be based on a short-period observation near the center of the observation cylinder rather than on the entire 60-nautical-mile diameter, and it is probably justifiable to regard them as discrete events.

The requirement of independence of repeated trials obviously is not fulfilled because of the short distance between successive observations as compared with the large-scale cloud systems. Although not independent, the observations are still unbiased, because the flight tracks, times of flight, and observation procedure were established in advance and were not modified significantly because of existing weather conditions. Therefore, the ratios provide unbiased estimates of the probabilities, although the reliability of the estimates is less than the number of observations would indicate.

Icing-to-cloud ratio as a function of temperature. - At temperatures appreciably below freezing, the icing-to-cloud ratio x/n represents the fraction of the clouds penetrated that contained liquid-water droplets, the remainder that did not cause icing being composed entirely of ice crystals. Since the probability of the formation of ice crystals in clouds increases as the temperature is reduced, the ratio x/n should be primarily a function of temperature. Figure 2 shows the average relation between icing-to-cloud ratio and temperature as revealed by table III. The rapid decrease of the icing-to-cloud ratio and the associated icing probability with decreasing temperature is clearly evident from these data. Data from temperatures of 0° to -2° C are not included in figure 2, because kinetic heating frequently prevents icing in this temperature range.

An examination of table III reveals wide variations in the individual values of x/n from the average values of figure 2. Application of statistical tests shows that these variations are considerably larger than would be expected from random sampling if the true value of x/n were a function of temperature alone. Moreover, the variations in x/n are not distributed at random. Since certain areas and seasons have consistently plus or minus departures from the over-all average values, perhaps the icing-to-cloud ratio is not a function of temperature alone but is also a function of season, altitude, and geographical location.

Seasonal and altitude effects. - Over-all seasonal and altitude effects are shown in figure 3, which presents separate curves showing the variations with temperature of cloud probability n/N, icing probability x/N, and icing-to-cloud ratio x/n for the four seasons and the two principal flight levels, 700 and 500 millibars. In the interpretation of these results it should be noted that the apparent seasonal variations are influenced to an unknown extent by climatological relations that exist between season, altitude, and geographical location.

Because of climatic factors, the various geographical areas are not represented equally for all seasons at a given temperature, or for all temperatures at a given season. For example, the data sample for winter at 500 millibars at -20° C contains 5 observations from "Ptarmigan" track and 959 observations from "Lark." On the other hand, the summer sample at the same altitude and temperature contains 1031 observations from "Ptarmigan" and 194 observations from "Lark." The difference in the corresponding values of the ratios may be due to geographical rather than to seasonal effects. Similar interactions exist when the data are classified with respect to geographical areas instead of season, making it difficult to separate the effects of the various factors.

Some significant features, however, are discernible in figure 3. The icing-to-cloud ratio at 500 millibars decreases continuously with decreasing temperature for all seasons, and it generally has maximum values in winter and minimum values in spring. The 700-millibar data, on the other hand, fail to show a continuous decrease of icing-to-cloud ratio with decreasing temperature except in spring. For spring, the x/n curve of 700 millibars parallels the 500-millibar curve, but the actual values are lower at all temperatures. In other seasons at 700 millibars, however, there is a consistent tendency for an increase in the icing-to-cloud ratio near the lower end of the seasonal temperature range.

Seasonal patterns of clouds and icing for various areas at 700 millibars. - In figure 4 are presented graphs showing seasonal variations in (1) icing probability x/N, (2) cloud probability n/N, (3) icing-to-cloud ratio x/n, for all tracks for which 700-millibar data for the entire year are included in table IV, and (4) average 700-millibar temperature. The values shown for the three ratios are over-all values including observations at all temperatures, both above and below freezing. For most of the areas and seasons included in this study, the temperature at 700 millibars was above freezing at least part of the time. This fact is reflected in the over-all values of icing probability x/N, since a larger percentage of observations above freezing leads to a lower icing probability. Icing probabilities can exist, however, when the average temperatures are above freezing. The data presented in this way show the practical utility of the over-all ratio x/N as a measure of icing probability for a given season and altitude.

Tracks "Eagle" and "Lark" are both in the eastern ocean areas, under the influence of the oceanic anticyclones during summer and frequent cyclonic storms in winter. They are characterized by a minimum of cloudiness in summer and a maximum in winter. Both have relatively low icing probabilities, with a maximum in winter or spring and with little or no icing in summer. Since the mean temperatures are close to freezing, the over-all icing-to-cloud ratios are inversely related to temperature.

"Buzzard Delta" track also has a maximum of cloudiness in winter combined with a lower average temperature than that of "Eagle" and "Lark." These circumstances give rise to a very high icing probability. In summer, the temperature is above freezing most of the time, and the cloudiness is less than in winter; hence, the icing probability is very low.

"Loon" track at 700 millibars is characterized by a high probability of cloudiness throughout the year with relatively small seasonal variations. The icing probability and icing-to-cloud ratio also show relatively small seasonal changes in spite of a rather large seasonal variation in temperature.

Conditions on "Ptarmigan" track are unique among the areas studied since this track does not lie over open water but over the polar ice cap. The surface is covered with snow and ice in winter and spring and consists of melting ice in summer, with open water along the southern portions of the track. Thus, the surface temperature in summer and early fall is near 0° C, and in winter and early spring it is much colder. The very low probabilities of icing in winter and spring are the result of low temperatures combined with low probabilities of cloudiness.

Seasonal patterns at 500 millibars. - At the 500-millibar level, temperatures are predominantly below freezing over practically all the ocean areas of the world. Most of the areas and seasons included in this study were entirely below freezing, and even the warmest were below freezing in over 95 percent of the observations (table III). Thus, the percentage of observations above freezing is not a significant factor in determining the icing probability at 500 millibars.

The tracks at 500 millibars may be divided into two groups depending on the season of occurrence of the maximum probability of icing and cloudiness, as follows:

(1) Group A; maximum icing in summer, maximum cloudiness in spring or summer: Vulture I, Buzzard Kilo, Buzzard Delta, Loon, and Ptarmigan

(2) Group B; maximum icing in fall, maximum cloudiness in winter or spring: Petrel, Lark, and Gull

The seasonal variations in (1) icing probability, (2) cloud probability, (3) icing-to-cloud ratio, and (4) average temperature are shown for the 500-millibar level in figure 5. The data from the three "Gull" tracks are combined because no one of the Gull tracks had data for the entire year. Although there is considerable variation within each group, the over-all patterns are fairly consistent. For group A, the annual variations of cloudiness, icing, and temperature are approximately in phase. For group B, the cloudiness and temperature are nearly opposite in phase, and the icing maximum tends to occur before the maximum of cloudiness. Except for "Vulture" and "Petrel," the icing-to-cloud ratio generally follows the annual variation of temperature.

Frequency and Extent of Icing Encounters

Data on the frequency and extent of icing encounters are presented in table V(a). For each flight track, season, and altitude, the table includes frequency distributions of the following three quantities:

(1) Horizontal extent of individual icing encounters

(2) Total distance in icing on each flight (at given flight level)

(3) Number of encounters on each flight (at given flight level)

The items presented in table V(a) were obtained directly from the flight data. The numbers in the table are the actual counts of the cases in each category, with the exception of the flight length and the number of flights with no icing. The length of flight was taken as the number of regular reporting positions at the given flight level, multiplied by 100 nautical miles. The total number of flights was found by dividing the total number of observations by the number of reporting positions, and the number of flights with no icing was obtained by subtracting the number with icing from this total. Thus, incomplete flights were translated into an equivalent number of complete flights.

Probability of encountering icing in flight of given length. - For flight planning, design, and mission analysis, it is desirable to know the probability of encountering icing a given number of times on a flight of a given length, and the probable extent of icing when it is encountered. The probability of any particular number of icing encounters for the 500- or 700-millibar portion of a particular flight track may be estimated from the frequency distribution of the encounters per flight (table V(a)). Because of the small number of cases in each data group, however, the statistical reliability of these estimates is rather poor. Moreover, the probabilities estimated in this way are applicable only to the particular length of flight for which data were obtained. Estimates of higher reliability and more general applicability may be obtained by establishing a relation between the percentage of flights with various numbers of icing encounters and the average number of encounters per flight.

This relation is shown in figure 6, in which the percentages of flights with at least one, two, and three icing encounters j are plotted as functions of the average number of icing encounters per flight m. Each data point in figure 6 represents combined data from two or more groups having nearly the same value of m (except the last point on the right, which represents only one data group). The reliability of the individual data points is indicated by vertical-line segments representing a range of one standard deviation of each side of the sample value. The empirical curves are drawn to represent estimated average relations based on the data points. Any vertical line from top to bottom in figure 6 is divided by these curves into four parts representing the probability of 0, 1, 2, and 3-or-more icing encounters on a flight for which the average number of encounters is given by the abscissa.

Theoretical curves computed from Poisson's distribution equation (ref. 2) are also shown in figure 6. These curves show the probability of at least 1, 2, and 3 occurrences of an event in n independent trials, each having a probability of p, when n is large and p is small; the product $np = m$ is the abscissa. The differences between the empirical and theoretical curves result from the fact that the individual encounters are not independent. Because of the large scale of the major synoptic weather systems, there is a tendency for either clear or cloudy weather to occur over a large area. Once icing is encountered, therefore, the probability of a second encounter is greater than it would be if the icing areas were distributed at random.

The empirical curves in figure 6 may be used to obtain an estimate of the probability of encountering icing at least once or twice in a flight of any length, in an area for which the average frequency of encountering icing is known. The average frequency of encountering icing, which was obtained by dividing the total number of encounters by the total distance flown at a given flight level, is given in table V(b) as the number of icing encounters per 1000 miles of flight. The product of this number and the length of a proposed flight in thousands of miles gives the expected (average) number of icing encounters m.

For example, to estimate the risk of icing on a flight of 800 miles at 700 millibars over the Bering Sea ("Loon" track) in summer, the expected number of icing encounters is given by $m = 0.775 \times 0.8 = 0.62$. From the empirical curves of figure 6, it is found that, for $m = 0.62$, the probability of at least one icing encounter is 0.43, the probability of two or more encounters is 0.15, and the probability of 3 or more encounters is 0.03. The probability of no icing is given by $1 - 0.43 = 0.57$. The probability of exactly one encounter is $0.43 - 0.15 = 0.28$. The probability of two encounters is $0.15 - 0.03 = 0.12$. The estimated probabilities presented in the last four columns of table V(b) were obtained in this manner. For values of m greater than 1.5, the probabilities given in table V(b) were calculated from Poisson's equation.

<u>Probable extent of icing encountered</u>. - In addition to knowing the probability of encountering icing, it is also useful to know the probable extent of icing when encountered. This information is also presented in table V(b), which lists the average length of icing encounters and selected values from the frequency distributions of length of icing encounters as follows:

Lower quartile	Exceeded in 75 percent of encounters
Median	Exceeded in 50 percent of encounters
Upper quartile	Exceeded in 25 percent of encounters
90th Percentile	Exceeded in 10 percent of encounters

These values were determined by approximating the cumulative frequency distributions (table V(a)) with smooth curves. The results are fairly reliable for the groups with large amounts of data, such as the "Buzzard" tracks, but are only rough estimates for the small samples.

Probability of Flight in Icing

The probability of flight in icing was discussed in a previous section where the ratio x/N (table IV), based on discrete observations, was used as an estimate of the probability. A different (though not independent) estimate of the over-all probability of icing for each data group was determined from the analysis of frequency and extent of icing encounters. This estimate (miles of icing per 100 miles of flight, table V(b)), which was obtained from a summation of the lengths of the individual icing encounters, utilizes the additional information in the original data on the beginning and ending of icing between reporting positions.

A comparison of the two estimates is shown in figure 7, which gives an indication of the consistency, though not the absolute accuracy, of the estimates. The agreement is sufficiently good to lend some support to the assumption made previously, that the duration of the individual observations was small compared with the interval between them. Because of the more complete utilization of the available information, the value of miles of icing per 100 miles of flight is regarded as the more reliable of the two estimates.

Type and Intensity of Icing

The observer, in reporting the type of ice that formed on the aircraft, distinguished among rime ice, clear ice, a combination of rime and clear ice, and frost. For the 4600 icing observations (including icing reported both at and between reporting positions), 72 percent were called rime ice, 10 percent clear ice, 17 percent a combination of both, and 1 percent frost. The reporting of frost, which was defined as icing in clear air, can be considered questionable, since this small percentage of the total observations is within the range of inherent coding and analysis errors considered for the over-all data.

Icing in precipitation, either rain or snow, occurred in about 20 percent of the icing conditions. About 55 percent of the icing in precipitation was reported while flying in snow. The remaining encounters were reported in rain and drizzle (30 percent) and in showers (15 percent). The occurrence of freezing rain was not reported as such and could not be clearly determined from the observational data. Practically all the reports of icing in precipitation also established that the aircraft were in clouds at the time; supercooled clouds could thus have been responsible for the icing rather than the reported rain or drizzle. The relatively infrequent occurrence of icing in precipitation shown by these data verifies the generally established criterion (ref. 3) that icing is less probable in precipitation areas.

The intensity of icing was reported for the most part in qualitative categories of light, moderate, and heavy. A quantitative rate-of-icing table provided in the code was seldom used. The intensity categories were defined on the basis of the effects of the icing on the aircraft (ref. 1). Ice accumulations that could be handled adequately by the ice-protection equipment and that did not necessitate changes in course, altitude, or airspeed were coded as light icing; whereas, icing that exceeded the capacity of the protection system and, if continued, would be a serious hazard to the flight was interpreted as heavy icing. An intermediate icing condition was labeled as moderate icing. The frequency of these reported intensities, related to the total observations, was tabulated as follows: light icing, 87 percent; moderate icing, 12 percent; and heavy icing, 1 percent.

Quantitative values may be applied to these intensity categories by referring to previous measurements of total ice accumulations experienced on domestic air routes, as measured by NACA pressure-type icing-rate meters (ref. 4). The total accumulation of ice from an icing encounter was found useful as a criterion of icing conditions in terms of the effects on the aircraft (loss of airspeed, etc.). If it is assumed that the frequency of icing intensities is the same for domestic and ocean areas, the measurements of ice accretions previously reported for domestic routes can be used.

Figure 8 shows a plot of the probability of exceeding finite ice accretions during a given icing encounter, measured by icing-rate meters on domestic air routes reported in reference 4. If the probabilities of the three intensity categories are assumed to be the same as the measured probabilities shown on the curve, light icing would include ice accretions up to about $1\frac{1}{2}$ inches, with moderate icing ranging between $1\frac{1}{2}$ and 5 inches, and heavy icing exceeding 5 inches. The limits of light icing, as noted from the pilot comments in reference 4, were also about $1\frac{1}{2}$ to 2 inches ice accretion. (The reconnaissance aircraft and those used on the domestic routes used similar ice-protection equipment.) It should be noted that these values were obtained by integrating the accretion rates measured on the small sensing probe of the icing-rate meter. Actual total ice thickness, particularly on airplane wings, would be much less because of the lower collection efficiency of larger bodies.

CONCLUDING REMARKS

The data included in this report are restricted to specific flight levels and selected areas of the oceans. Further application of these results to the operational analysis of specific missions or to the formulation of ice-protection design requirements would require a method for extending the results to apply to ocean areas in general. No direct and simple correlations were immediately evident between the icing probabilities and the many variables existing in the over-all data of this report. The effects of altitude, geographical location, and climatic factors such as seasonal variations in cloudiness and temperature are all interrelated in such a way that classification of the data in terms of one variable is influenced by the correlated variations in other variables.

A preliminary study indicated that a limited extension of the icing probabilities to other ocean areas may be possible if based on known climatology of the areas involved. However, further analysis, beyond the scope of this report, will be required.

In general, icing statistics obtained from flight data are strongly influenced by the flight procedures dictated by a particular mission and by pilot practices used in the operation of the aircraft. In airline operation or on certain Air Force missions, any meteorological conditions considered hazardous or of adverse effect on flight progress are avoided, if possible, by allowable changes in schedule, course, or altitude, Therefore, these conditions are not completely experienced, and data from such operations, if used, would produce a statistical bias. The results presented in this report are essentially unbiased in this respect, since the missions were flown primarily to determine weather factors and were not altered from routine procedures to avoid adverse conditions unless necessary for the safety of the flight. As compared with airline experience, the high icing probabilities (up to 7 percent) recorded for some areas during certain seasons are a result of combining a greater existence of icing conditions in those areas with unbiased statistics from the flight operations that supplied the data.

The significant results pointed out in this study are the large variation of icing probabilities (0 to 0.07) that was shown to exist over ocean areas throughout the year. Also, the general tendency of colder cloud temperatures to reduce the probability of icing in equally cloudy conditions is of interest, since this establishes over-all values for a relation known to exist through previous experience and research.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, March 22, 1957

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2. Hoel, Paul G.: Introduction to Mathematical Statistics. John Wiley & Sons, Inc., 1947.

3. Kline, Dwight B., and Walker, Joseph A.: Meteorological Analysis of Icing Conditions Encountered in Low-Altitude Stratiform Clouds. NACA TN 2306, 1951.

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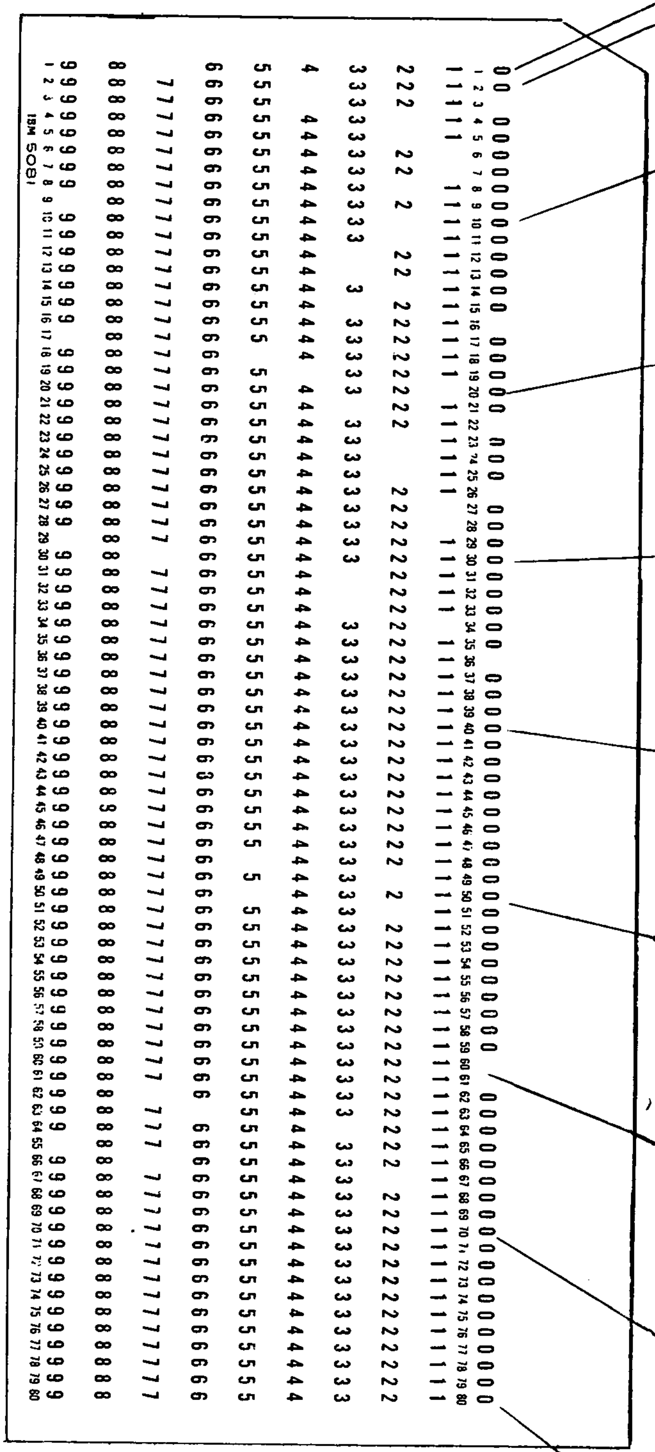
TABLE I. - SUMMARY OF COMPLETE METEOROLOGICAL OBSERVATIONS AS RECORDED ON PUNCHED CARDS FOR MACHINE ANALYSIS



Card column	
1	Squadron
2	Track
3	Day
4	Month
5	Year
6 7	Observation number
8 9 10	Time
11	Octant - radar
12 13	Latitude
14 15	Longitude
16 17 18	Altitude
19	Flight conditions
20	Relative wind
21 22	Wind direction
23 24	Wind speed
25	Present weather
26	Remarks on present weather
27	Past weather
28	Turbulence
29	Oblique visibility
30	Horizontal visibility
31	Quadrant weather North
32	Quadrant weather East
33	Quadrant weather South
34	Quadrant weather West
35	Number of cloud layers
36	Cloud amount Layer 1
37	Cloud amount Layer 2
38	Cloud type layer 1
39 40	Height of base of cloud (1)
41 42	Height of top of cloud (2)
43	Cloud type layer 2
44 45	Height of base of cloud (2)
46 47	Height of top of cloud (2)
48 49	Temperature
50 51	Dewpoint
52	Ice rate
53	Type of ice
54	Distance to beginning of ice
55	Distance to end of ice
56 57	Altitude of base of ice
58 59	Altitude of top of ice
60	Significant weather change
61	Distance to weather off course
62	Weather off course
63	Bearing of weather off course
64	Index to altitude correction "D"
65 66 67	"D" value
68 69	Bearing of echo center
70	Distance to echo center
71	Orientation of ellipse
72	Echo width
73	Length of major axis
74	Character of echo
75	Tendency of echo area
76	Intensity of echo
77	Type wind
78	Flight number
79	Number of card
80	Remarks on past weather

TABLE II. - GROUPING AND NUMBER OF WEATHER RECONNAISSANCE OBSERVATIONS

USED FOR STATISTICAL STUDY

Track	Flight level	Spring					Summer					Fall					Winter					Total
		Year				Total	Year				Total	Year				Total	Year				Total	
		1952	1953	1954	1955		1952	1953	1954	1955		1952	1953	1954	1955		1952	1953	1954	1955		
Vulture I	500 mb	X	X	X	-	2088	X	X	-	-	2176	X	X	-	-	1852	X	X	X	-	1940	8,056
	1500 ft	X	X	-	-	869	X	X	-	-	1079	X	X	-	-	871	X	X	-	-	659	3,478
Vulture II	700 mb	X	X	-	-	358	X	X	-	-	234	X	X	-	-	466	X	X	-	-	293	1,351
	1500 ft	X	X	-	-	2281	X	X	-	-	2168	X	X	-	-	1922	X	X	-	-	1386	7,757
Buzzard Kilo	500 mb	X	X	X	-	2486	X	X	-	-	2395	X	X	-	-	2386	X	X	X	-	2082	9,349
	1500 ft	X	X	X	-	1256	X	X	-	-	1428	X	X	-	-	1269	X	X	X	-	1140	5,093
Buzzard Delta	500 mb	X	X	X	-	3464	X	X	-	-	2368	X	X	-	-	2356	X	X	X	-	1930	10,118
	700 mb	X	X	X	-	2521	X	X	-	-	1804	X	X	-	-	1914	X	X	X	-	1547	7,786
Loon	500 mb	X	X	X	X	3760	X	X	X	X	2886	X	X	X	-	3597	X	X	X	X	3462	13,705
	700 mb	-	-	X	X	1320	-	-	X	X	852	-	-	X	-	817	-	-	X	X	740	3,729
Ptarmigan	500 mb	X	X	X	X	3434	X	X	X	X	3204	X	X	X	-	3246	X	X	X	X	2694	12,578
	700 mb	-	-	X	X	1309	-	-	X	X	714	-	-	X	-	657	-	-	X	X	753	3,433
Gull I	500 mb	X	X	-	-	1129	X	X	-	-	443	-	-	-	-	----	X	X	-	-	875	2,447
	700 mb	X	X	-	-	305	-	-	-	-	----	-	-	-	-	----	X	X	-	-	671	976
	1500 ft	X	X	-	-	417	-	-	-	-	----	-	-	-	-	----	X	X	-	-	420	837
Gull II	500 mb	X	X	-	-	1750	X	X	-	-	519	-	-	-	-	----	-	-	-	-	----	2,269
Gull III	500 mb	-	-	-	-	----	X	X	-	-	492	X	X	-	--	369	-	-	-	-	----	861
	700 mb	-	-	-	-	----	X	X	-	-	1085	X	X	-	-	895	-	-	-	-	----	1,980
	1500 ft	-	-	-	-	----	X	X	-	-	1267	X	X	-	-	1021	-	-	-	-	----	2,288
Lark	500 mb	X	X	X	-	2028	X	X	-	-	3044	X	X	-	-	2376	X	X	X	-	2728	10,176
	700 mb	X	X	-	-	106	-	-	-	-	----	X	X	-	-	224	X	X	-	-	182	512
	1500 ft	X	X	X	-	1710	X	X	-	-	2456	X	X	-	-	1978	X	X	X	-	2236	8,380
Petrel I	500 mb	X	X	X	-	2140	X	X	-	-	1406	X	X	-	-	1250	X	X	X	-	2342	7,138
	700 mb	X	X	-	-	198	-	-	-	-	----	-	-	-	-	----	X	X	-	-	266	464
	1500 ft	X	X	X	-	1008	X	X	-	-	694	X	X	-	-	563	X	X	X	-	1030	3,295
Petrel II	500 mb	X	X	-	-	555	X	X	-	-	654	X	X	-	-	284	X	X	-	-	876	2,369
	1500 ft	X	X	-	-	253	X	X	-	-	330	X	X	-	-	134	X	X	-	-	380	1,097
Falcon	500 mb	-	-	X	-	1046	-	-	-	-	----	-	-	-	-	----	-	-	X	-	339	1,385
	1500 ft	-	-	X	-	1039	-	-	-	-	----	-	-	-	-	----	-	-	X	-	261	1,300
Eagle	700 mb	X	X	X	-	546	X	X	-	-	365	X	X	-	-	346	X	X	X	-	278	1,535
Total						39,376					34,063					30,793					31,510	135,742

TABLE III. - TABULATION OF TOTAL, CLOUD, AND ICING OBSERVATIONS WITH CORRESPONDING RATIOS AT 5° TEMPERATURE INTERVALS

[Observations: N, total; n, clouds; x, icing. Dashed lines denote insufficient data.]

Season	Flight level	Track	Temperature, °C																																															
			18° to 22°						13° to 17°						8° to 12°						3° to 7°						-2° to 2°						-7° to -3°						-12° to -8°						-17° to -13°					
			Observations			Percent			Observations			Percent			Observations			Percent			Observations			Percent			Observations			Percent			Observations			Percent			Observations			Percent			Observations			Percent		
			N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$
Spring	500 mb	Vulture I																									30	1	0	3	0	--	1193	90	45	8	4	50	733	81	45	11	6	56	91	13	3	14	3	23
		Buz Kilo																									1	1	1	--	--	--	220	77	32	35	15	42	690	113	44	16	6	39	747	87	18	12	2	21
		Buz Delta																									2	0	0	--	--	--	14	7	0	50	0	--	107	29	12	27	11	41	511	124	22	24	4	18
		Loon																																					2	2	0	--	--	--	46	24	2	52	4	8
		Ptarmigan																																																
		Gull I																									1	0	0	--	--	--	37	6	3	16	8	--	434	42	13	10	3	31	415	53	7	13	2	13
		Gull II																															31	1	0	3	0	--	725	54	13	7	2	24	718	77	8	11	1	10
		Lark																									1	0	0	--	--	--	15	0	0	0	0	--	143	9	3	6	2	--	598	78	6	13	1	8
		Petrel I																									5	1	0	--	--	--	173	17	7	10	4	41	781	42	18	5	2	43	837	94	23	11	3	24
		Petrel II																															38	0	0	0	0	--	309	13	0	4	0	0	192	13	0	7	0	0
		Falcon																																					9	0	0	--	--	--	29	1	0	3	0	--
	700 mb	Buz Delta													2	0	0	--	--	--	55	10	0	18	0	0	311	86	1	28	<1	1	626	161	39	26	6	24	689	118	27	17	4	23	601	78	7	13	1	9
		Loon																															86	25	12	29	14	48	433	100	20	23	5	20	493	107	14	22	3	13
		Ptarmigan																									3	0	0	--	--	--	19	6	0	32	0	--	105	10	3	10	3	30	275	37	6	13	2	16
		Gull I							3	0	0	--	--	--	10	0	0	0	0	--	107	10	0	9	0	0	102	22	0	22	0	0	38	7	1	18	3	--	31	8	3	26	10	--	8	3	0	--	--	--
		Lark	1	0	0	--	--	--	2	0	0	--	--	--	5	1	0	--	--	--	14	1	0	7	0	--	10	1	0	10	--	--	31	10	1	32	3	10	13	0	0	0	0	--	23	1	1	4	4	--
		Eagle													13	0	0	0	0	--	103	4	0	4	0	--	243	34	2	14	<1	6	152	37	11	24	7	30	26	10	2	38	8	20	5	1	0	--	--	--
	1500 ft	Falcon	12	0	0	0	--	--	44	0	0	0	0	--	73	1	0	1	0	--	345	114	0	33	0	0	427	133	11	31	3	8	92	28	10	30	11	36	33	11	1	33	3	9	12	4	3	33	25	--
Summer	500 mb	Vulture I																									183	24	11	13	6	46	1846	223	73	12	4	33	96	12	4	12	4	33						
		Buz Kilo							1	0	0	--	--	--	19	0	0	0	0	--	4	0	0	--	--	--	306	25	5	8	2	20	1498	296	138	20	9	47	422	56	27	13	6	48	124	11	1	9	<1	9
		Buz Delta																									77	12	2	16	3	17	691	119	59	17	9	50	811	99	34	12	4	34	493	37	6	8	1	16
		Loon																									3	0	0	--	--	--	35	8	3	23	9	--	387	70	14	18	4	20	1082	177	23	16	2	13
		Ptarmigan																																					7	2	0	--	--	--	170	26	2	15	1	8
		Gull I																															174	12	6	7	3	50	250	17	6	7	2	35	9	1	0	--	--	--
		Gull II																									6	0	0	--	--	--	192	3	1	2	<1	--	317	12	6	4	2	50	4	1	0	--	--	--
		Gull III																									1	0	0	--	--	--	323	13	5	4	2	38	152	19	4	12	3	21	1	0	0	--	--	--
		Lark																									3	0	0	--	--	--	413	7	4	2	<1	--	1581	79	23	5	1	29	801	44	10	5	1	23
		Petrel I																									4	0	0	--	--	--	226	3	2	1	<1	--	972	54	14	6	1	26	186	17	0	9	0	0
		Petrel II																															144	10	1	7	<1	10	478	47	15	10	3	32	30	1	0	3	0	--
	700 mb	Buz Delta							10	0	0	0	0	--	523	46	0	9	0	0	672	77	0	11	0	0	387	50	0	13	0	0	171	36	13	21	8	36	29	1	0	3	0	--	1	0	0	--	--	--
		Loon													2	0	0	--	--	--	116	14	0	12	0	0	268	47	4	18	1	9	363	75	26	21	7	35	77	20	11	26	14	55	12	3	0	25	0	--
		Ptarmigan																			8	0	0	--	--	--	100	10	2	10	2	20	322	50	23	16	7	46	269	26	12	10	4	46	15	6	4	40	27	--
		Eagle							2	0	0	--	--	--	83	1	0	1	0	--	237	12	0	5	0	0	38	3	0	8	0	--	3	0	0	--	--	--												
Fall	500 mb	Vulture I																			2	0	0	--	--	--	57	8	1	14	2	--	1603	134	45	8	3	34	165	9	6	5	4	--	2	1	0	--	--	--
		Buz Kilo																			3	0	0	--	--	--	64	13	4	20	6	31	734	122	56	17	8	46	704	116	49	16	7	42	564	41	16	7	3	39
		Buz Delta																									14	2	1	14	7	--	170	53	24	31	14	45	329	68	25	21	8	37	474	63	11	13	2	17
		Loon																															3	1	0	--	--	--	51	17	3	33	6	18	243	38	3	15	1	8
		Ptarmigan																																											2	1	0	--	--	--
		Gull III																									16	1	0	6	0	--	239	19	8	8	3	42	113	12	2	11	2	17						
		Lark																									1	0	0	--	--	--	129	4	4	3	3	--	809	42	13	5	2	31	765	119	24	16	3	20
		Petrel I																									5	0	0	--	--	--	256	17	13	7	5	76	599	57	18	10	3	32	288	55	10	19	3	18
		Petrel II																									3	0	0	--	--	--	61	4	2	7	3	--	158	22	11	14	7	50	49	11	6	22	12	55
	700 mb	Buz Delta							1	0	0	--	--	--	51	5	0	10	0	--	261	33	0	13	0	0	484	53	1	11	<1	2	395	67	27	17	7	40	259	32	8	12	3	25	193	31	6	16	3	19
		Loon																			19	7	0	37	0	--	86	25	2	29	2	8	137	26	9	19	7	35	165	34	10	21	6	29	298	46	8	15	3	17
		Ptarmigan																			1	0	0	--	--	--	8	0	0	--	--	--	35	12	4	34	11	33	84	13	4	15	5	31	168	20	7	12	4	35
		Lark	6	0	0	--	--	--	23	3	0	13	0	--	14	3	0	21	0	--	34	3	0	9	0	--	57	6	0	11	0	--	48	10	2	21	4	20	26	0	0	0	0	--	13	4	1	31	8	--
		Eagle													21	1	0	5	0	--	161	9	0	6	0	--	131	17	1	13	<1	6	30	10	2	33	7	20												
Winter	500 mb	Vulture I																			3	0	0	--	--	--	40	1	1	3	3	--	950	33	20	3	2	61	709	46	24	6	3	52	187	17	9	9	5	53
		Buz Kilo																															14	5	0	36	0	--	200	24	14	12	7	58	426	53	21	12	5	40
		Buz Delta																																					2	0	0	--	--	--	31	6	0	19	0	--
		Loon																																					1	0	0	--	--	--	4	0	0	--	--	--
		Ptarmigan																																																
		Gull I																															11	1	0	9	0	--	223	10	6	4	3	60	384	43	10	11	3	23
		Lark																															16	0	0	0	0	--	120	11	4	9	3	36	864	131	23	15	3	18
		Petrel I																									1	0	0	--	--	--	64	1	0	2	0	--	556	60	21	11	4	35	874	195	41	22	5	21
		Petrel II																									1	0	0	--	--	--	47	3	3	6	6	--	293	38	12	13	4	32	313	67	18	21	6	27
		Falcon																																											3	2	0	--	--	--
	700 mb	Buz Delta																			1	0	0	--	--	--	27	4	1	15	4	--	84	24	15	29	18	62	165	31	17	19	10	55	338	69	26	20	8	38
		Loon																									2	0	0	--	--	--	29	13	4	45	14	31	77	29	5	38	6	17	254	66	13	26	5	20
		Ptarmigan																																					2	0	0	--	--	--	28	2	0	7	0	--
		Gull I	1	0	0	--	--	--	4	0	0	--	--	--	3	0	0	--	--	--	152	10	0	7	0	0	301	61	9	20	3	15	144	25	14	17	10	56	47	4	4	9	9	--	18	6	2	33	11	--
		Lark							12	2	0	17	0	--	7	1	0	--	--	--	28	0	0	--	0	--	31	5	0	16	0	--	42	11	4	26	10	36	31	5	0	16	0	--	17	1	0	6	0	--
		Petrel I	2	0	0	--	--	--	1	0	0	--	--	--	28	0	0	0	0	--	75	5	0	7	0	--	80	11	0	14	0	0	43	13	0	30	--	--	14	1	1	7	7	--	4	1	1	--	--	--
		Eagle																			16	3	0	19	0	--	139	18	2	13	1	11	73	18	4	25	5	22	11	5	1	45	9	--	1	0	0	--	--	--
	1500 ft	Lark	15	0	0	0	--	--	133	26	0	20	0	0	875	307	0	35	0	0	875	215	0	25	0	0	237	53	0	22	0	0	29	11	1	38	3	9	4	4	0	--	--	--						
		Falcon													1	1	0	--	--	--	42	14	0	33	0	0	180	40	9	22	5	22	36	10	4	28	11	40	1	0	0	--	--	--	1	0	0	--	--	--

TABLE III. - CONCLUDED. TABULATION OF TOTAL, CLOUD, AND ICING OBSERVATIONS WITH CORRESPONDING RATIOS AT 5° TEMPERATURE INTERVALS

[Observations: N, total; n, clouds; x, icing. Dashed lines denote insufficient data]

Season	Flight level	Track	Temperature, °C																																									
			-22° to -18°						-27° to -23°						-32° to -28°						-37° to -33°						-42° to -38°						-47° to -43°						-52° to -48°					
			Observations			Percent			Observations			Percent			Observations			Percent			Observations			Percent			Observations			Percent			Observations			Percent			Observations			Percent		
			N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$	N	n	x	$\frac{n}{N}$	$\frac{x}{N}$	$\frac{x}{n}$
Spring	500 mb	Vulture I	2	0	0	--	--	--																																				
		Buz Kilo	418	43	3	10	<1	7	277	23	0	8	0	0	108	5	0	5	0	--	21	2	0	10	0	--	3	0	0	--	--	--												
		Buz Delta	825	164	20	20	2	12	954	184	9	19	<1	5	659	89	0	14	0	0	293	20	0	7	0	0	97	6	0	6	0	--	2	0	0	--	--	--						
		Loon	392	113	5	29	1	4	933	205	7	22	<1	4	1176	183	4	16	<1	2	847	109	0	13	0	0	295	10	0	3	0	0	58	0	0	0	0	--	1	0	0	--	--	--
		Ptarmigan	52	3	0	6	0	0	440	21	1	5	<1	5	805	74	1	9	<1	1	847	63	0	7	0	0	882	36	0	4	0	0	350	11	0	3	0	0	44	0	0	0	0	--
		Gull I	146	19	0	13	0	0	67	6	0	9	0	--	14	0	0	0	0	--	3	0	0	--	--	--																		
		Gull II	213	26	0	12	0	0	48	8	1	17	2	--	12	1	1	8	8	--	1	0	0	--	--	--																		
		Lark	684	96	11	14	2	11	353	35	3	10	<1	9	165	10	0	6	0	0	41	3	0	7	0	--																		
		Petrel I	241	35	3	15	1	9	53	5	0	9	0	--	6	1	0	--	--	--																								
		Petrel II	15	5	2	33	13	--	1	0	0	--	--	--																														
		Falcon	221	11	1	5	<1	9	356	20	1	6	<1	5	246	8	1	3	<1	--	137	2	0	1	0	--	43	1	0	2	0	--	5	0	0	--	--	--						
	700 mb	Buz Delta	166	14	2	8	1	14	62	6	0	10	0	--	9	2	0	--	--	--																								
		Loon	250	30	2	12	<1	7	51	11	0	22	0	0	4	0	0	--	--	--																								
		Ptarmigan	409	23	0	6	0	0	373	33	1	9	<1	3	105	6	0	6	0	--	16	0	0	0	0	--	4	0	0	--	--	--												
		Gull I	3	3	0	--	--	--																																				
		Lark	7	0	0	--	--	--																																				
	1500 ft	Falcon	1	0	0	--	--	--																																				
Summer	500 mb	Buz Kilo	19	2	0	11	0	--																																				
		Buz Delta	236	18	2	8	<1	11	45	2	1	4	2	--																														
		Loon	952	137	15	14	2	11	339	54	3	16	<1	6	80	5	0	6	0	--	4	1	0	--	--	--																		
		Ptarmigan	1031	140	14	14	1	10	1534	196	16	13	1	8	425	48	4	11	<1	8	24	2	0	8	0	--	2	0	0	--	--	--												
		Gull I	9	0	0	--	--	--	1	0	0	--	--	--																														
		Lark	194	8	2	4	1	25	35	0	0	0	0	--	1	0	0	--	--	--	1	0	0	--	--	--																		
		Petrel I	1	0	0	--	--	--																																				
		Petrel II	2	0	0	--	--	--																																				
	700 mb	Loon	12	0	0	0	--	--	2	0	0	--	--	--																														
Fall	500 mb	Buz Kilo	276	19	7	7	3	37	25	2	0	8	0	--	6	0	0	--	--	--																								
		Buz Delta	506	65	9	13	2	14	371	45	4	12	1	9	258	48	6	19	2	12	145	12	0	8	0	0	76	6	0	8	0	--	4	0	0	--	--	--	1	0	0	--	--	--
		Loon	510	89	9	17	2	10	865	171	8	20	<1	5	995	148	12	15	1	8	716	59	0	8	0	0	201	28	0	14	0	0	13	1	0	8	0	--						
		Ptarmigan	96	20	1	21	1	5	533	70	6	13	1	9	866	82	4	9	<1	5	979	46	1	5	<1	2	688	16	0	2	0	0	82	0	0	0	0	--						
		Lark	369	51	17	14	5	33	178	29	7	16	4	24	92	16	1	17	1	6	14	4	0	29	0	--																		
		Petrel I	67	15	4	22	6	27	16	2	0	12	0	--	11	0	0	0	0	--																								
		Petrel II	13	2	0	15	0	--																																				
	700 mb	Buz Delta	171	32	5	19	3	16	70	23	6	33	9	26	2	1	0	--	--	--																								
		Loon	102	15	1	15	<1	7	10	3	1	30	10	--																														
		Ptarmigan	215	28	11	13	5	39	116	14	7	12	6	50	27	0	0	0	0	--	3	0	0	--	--	--																		
Winter	500 mb	Vulture I	30	5	1	17	3	--	2	0	0	--	--	--																														
		Buz Kilo	569	35	10	16	2	29	455	30	3	7	<1	10	269	12	0	4	0	0	124	5	0	4	0	--	23	1	0	4	0	--												
		Buz Delta	128	30	12	23	9	40	259	36	4	14	2	11	439	69	14	16	3	20	517	63	5	12	<1	8	409	28	0	7	0	0	126	13	0	10	0	0	14	3	0	21	0	--
		Loon	85	31	6	36	7	19	355	68	2	19	<1	3	641	94	8	15	1	9	1140	108	2	9	<1	2	871	85	0	10	0	0	133	23	0	17	0	0						
		Ptarmigan	5	0	0	--	--	--	19	1	0	5	0	--	79	7	0	9	0	--	394	11	1	3	<1	9	1143	15	0	1	0	0	796	5	0	1	0	--	97	0	0	0	0	--
		Gull I	175	14	1	8	<1	7	60	4	0	7	0	--	7	0	0	--	--	--																								
		Lark	959	168	36	18	4	21	444	50	12	11	3	24	226	37	0	16	0	0	66	3	0	5	0	--	4	0	0	--	--	--												
		Petrel I	509	73	19	14	4	26	206	34	7	16	3	21	102	10	0	10	0	0	20	11	0	55	0	0																		
		Petrel II	142	14	3	10	2	21	61	5	0	8	0	--	13	1	0	8	0	--	2	0	0	--	--	--																		
		Falcon	15	0	0	0	0	--	88	4	3	5	3	--	112	3	1	3	<1	--	91	8	0	9	0	--	30	1	0	3	0	--												
	700 mb	Buz Delta	399	55	17	14	4	31	395	53	11	13	3	21	124	32	7	26	6	22	14	9	6	64	43	--																		
		Loon	255	43	9	17	4	21	112	6	0	5	0	--	11	0	0	0	0	--																								
		Ptarmigan	76	6	0	8	0	--	215	18	4	8	2	22	275	7	0	3	0	--	129	4	1	3	<1	--	25	0	0	0	0	--	2	0	0	--	--	--	1	0	0	--	--	--
		Lark	2	0	0	--	--	--																																				
		Petrel I	1	0	0	--	--	--																																				

TABLE IV. - SUMMARY TABULATION OF TOTAL, CLOUD, AND ICING OBSERVATIONS WITH CORRESPONDING RATIOS AND AVERAGE TEMPERATURES

[Observations: N, total; n, clouds; x, icing.]

Season	Flight level	Track	Summary total			Average percent			Average temperature		
			N	n	x	n/N	x/N	x/n	N	n	x
Spring	500 mb	Vulture I	2049	185	93	9.0	4.5	50	-7.2	-7.7	-7.5
		Buz Kilo	2485	351	98	14.1	3.9	28	-15.5	-12.7	-9.4
		Buz Delta	3464	623	63	18.0	1.8	10	-24.0	-21.9	-16.8
		Loon	3750	646	18	17.2	.5	3	-29.7	-27.0	-23.7
		Ptarmigan	3420	208	2	6.1	<.1	1	-34.8	-33.5	-27.5
		Gull I	1117	126	23	11.3	2.1	18	-14.1	-14.0	-11.3
		Gull II	1748	167	23	9.6	1.3	14	-13.7	-14.7	-13.5
		Lark	2000	231	23	11.6	1.1	10	-19.6	-19.2	-18.2
		Petrel I	2096	195	51	9.3	2.4	26	-13.1	-14.2	-11.9
		Petrel II	555	31	2	5.6	.4	6	-11.8	-13.4	-19.0
		Falcon	1046	43	3	4.1	.3	7	-26.7	-24.9	-25.3
	700 mb	Buz Delta	2521	475	76	18.8	3.0	16	-9.5	-7.4	-7.9
		Loon	1317	273	48	20.7	3.6	18	-14.1	-13.3	-10.5
		Ptarmigan	1309	115	10	8.8	.8	9	-20.4	-18.6	-14.9
		Gull I	302	53	4	17.5	1.3	8	.1	-2.8	-8.2
		Lark	106	14	2	13.2	1.9	14	-5.6	-3.8	-10.0
		Eagle	542	86	15	15.9	2.8	17	-.8	-3.2	-4.5
	1500 ft	Falcon	1039	291	25	28.0	2.4	9	2.2	0.8	-4.6
Summer	500 mb	Vulture I	2125	259	88	12.2	4.1	34	-4.7	-4.6	-4.7
		Buz Kilo	2393	390	171	16.3	7.1	44	-5.6	-5.2	-5.0
		Buz Delta	2353	287	104	12.2	4.4	36	-10.6	-8.8	-7.5
		Loon	2882	452	58	15.7	2.0	13	-17.4	-16.9	-14.9
		Ptarmigan	3193	414	36	13.0	1.1	9	-23.6	-23.1	-23.1
		Gull I	443	30	12	6.8	2.7	40	-8.3	-8.1	-7.6
		Gull II	519	16	7	3.1	1.3	44	-8.0	-10.0	-10.3
		Gull III	477	32	9	6.7	1.9	28	-6.8	-7.5	-7.1
		Lark	3029	138	39	4.6	1.3	28	-11.4	-12.2	-11.5
		Petrel I	1389	74	16	5.3	1.2	22	-9.8	-11.1	-9.6
		Petrel II	654	58	16	8.9	2.5	28	-9.1	-9.0	-9.2
	700 mb	Buz Delta	1793	210	13	11.7	0.7	6	4.2	3.2	-4.1
		Loon	852	159	41	18.7	4.8	26	-2.9	-3.5	-5.5
		Ptarmigan	714	92	41	12.9	5.7	45	-6.3	-6.4	-7.1
		Eagle	363	16	0	4.4	0	0	5.8	4.0	-----
Fall	500 mb	Vulture I	1829	152	52	8.3	2.8	34	-5.4	-5.0	-4.9
		Buz Kilo	2376	313	132	13.2	5.6	42	-10.7	-8.9	-8.6
		Buz Delta	2348	362	80	15.4	3.4	22	-20.0	-17.7	-12.4
		Loon	3597	550	35	15.3	1.0	6	-27.1	-26.3	-23.1
		Ptarmigan	3246	235	12	7.2	.4	5	-32.8	-29.3	-26.9
		Gull III	368	32	10	8.7	2.7	31	-6.6	-6.7	-5.9
		Lark	2357	265	66	11.2	2.8	25	-14.1	-17.4	-16.2
		Petrel I	1242	146	45	11.7	3.6	31	-11.1	-12.6	-11.2
		Petrel II	284	39	19	13.7	6.7	49	-10.1	-10.9	-10.6
	700 mb	Buz Delta	1887	277	53	14.7	2.8	19	-5.7	-7.6	-10.3
		Loon	817	156	31	19.1	3.8	20	-11.0	-9.4	-9.7
		Ptarmigan	657	87	33	13.2	5.0	38	-17.7	-16.2	-17.1
		Lark	221	29	3	13.1	1.4	10	.5	-.4	-7.7
		Eagle	343	37	3	10.8	.9	8	2.6	0	-2.3
Winter	500 mb	Vulture I	1921	102	55	5.3	2.9	54	-8.0	-9.4	-8.8
		Buz Kilo	2080	165	48	7.9	2.3	29	-21.4	-18.5	-15.2
		Buz Delta	1925	248	35	12.9	1.8	14	-33.0	-31.0	-26.6
		Loon	3230	409	18	12.7	.6	4	-34.3	-32.8	-26.2
		Ptarmigan	2533	39	1	1.5	<.1	3	-40.8	-37.2	-37.0
		Gull I	860	72	17	8.4	2.0	24	-15.3	-15.3	-13.3
		Lark	2699	400	75	14.8	2.8	19	-19.9	-19.6	-18.5
		Petrel I	2332	384	88	16.5	3.8	23	-15.7	-16.9	-15.8
		Petrel II	872	128	36	14.7	4.1	28	-14.4	-14.4	-12.8
		Falcon	339	18	4	5.3	1.2	22	-30.1	-29.2	-25.0
	700 mb	Buz Delta	1547	277	100	17.9	6.5	36	-18.9	-19.3	-16.8
		Loon	740	157	31	21.2	4.2	20	-17.6	-15.1	-14.7
		Ptarmigan	753	37	5	4.9	.7	14	-28.6	-25.2	-29.0
		Gull I	670	106	29	15.8	4.3	27	-1.0	-2.0	-4.9
		Lark	170	25	4	14.7	2.4	16	-2.5	-3.0	-4.7
		Petrel I	248	31	2	12.5	.8	6	1.2	-1.6	-13.5
		Eagle	240	44	7	18.3	2.9	16	-1.8	-3.0	-4.3
	1500 ft	Lark	2168	616	1	28.4	<.1	<1	7.1	7.3	-3.0
		Falcon	261	65	13	24.9	5.0	20	0	.3	-1.3

TABLE V. - FREQUENCY AND EXTENT OF ICING ENCOUNTERS

(a) DATA

Season	Flight level	Track	Approx. av. length of flight, nautical mile	Length of encounter, nautical mile									Distance in icing per flight, nautical mile											Number of encounters per flight						
				0-30	30-70	70-110	110-150	150-250	250-350	350-450	450-550	550-650	0	0-30	30-70	70-110	110-150	150-250	250-350	350-450	450-550	550-650	650-750	0	1	2	3	4	5	6
				Number of encounters									Number of flights											Number of flights						
Spring	500 mb	Vulture	1200	24	29	20	9	12	4	3			105	8	12	14	10	12	5	4	0	0	1	105	37	23	6			
		Buz Kilo	1300	19	25	16	9	15	5	3			123	7	20	13	4	13	7	2	0	0	2	123	48	16	4			
		Buz Delta	1400	16	21	11	6	8	4	1			198	7	11	9	7	9	4	2				198	38	7	1	3		
		Loon	1400	10	11	2	5	2					242	7	8	1	5	3						242	19	4	1			
		Ptarmigan	1400	2	1	0	1	1					239	2	1	0	1	1						239	5					
		Gull I	1100	4	9	4	6	3					77	4	8	4	5	4						77	24	1				
		Gull II	2500	2	5	7	3	2	2				50	2	5	5	3	3	2					50	19	1				
		Lark	1400	15	8	5	1	3	0	1			116	9	7	4	3	3	0	1				116	21	6				
		Petrel I	1700	10	15	12	5	5	6				86	5	7	7	3	8	6	0	1			86	23	12	2			
		Petrel II	1600	1	3	0	0	1					32	1	1	0	0	0	1					32	2	0	1			
		Falcon	1300	3	1	2							75	3	1	2								75	6					
	700 mb	Buz Delta	1300	26	30	21	12	14	1	0	1		116	16	17	15	10	12	6	1	0	1		116	54	21	3			
		Loon	900	46	41	16	2	6					73	18	27	9	13	6	1					73	43	26	4	1		
		Ptarmigan	900	10	7	2	1	1					129	5	7	1	2	1						129	12	3	1			
		Gull I	700	2	1	0	1	1					38	2	1	0	1	1						38	5					
		Lark	Only one reporting position during climb; horizontal extent not available																											
		Eagle	600	4	7	4	1	1	0	1			79	2	5	4	1	0	1	1				79	10	4				
	1500 ft	Falcon	1300	8	7	4	3	3					57	7	6	4	3	3						57	21	2				
Summer	500 mb	Vulture I	1200	37	30	10	8	11	3	2			113	16	12	7	7	15	4	3				113	44	12	2	4	1	1
		Buz Kilo	1300	38	43	22	18	25	5	2	1	1	85	12	21	12	13	21	12	6	0	2		85	54	38	3	4		
		Buz Delta	1400	34	30	20	11	21	3	0	1		86	17	16	11	7	22	4	2	3			86	55	18	7	2		
		Loon	1500	37	39	14	8	4	1	1			119	26	22	10	10	4	4	2				119	58	14	6			
		Ptarmigan	1300	30	31	7	3	1					191	18	19	9	5	3						191	41	9	3	1		
		Gull I	1100	0	2	4	0	1	0	0	1		33	0	2	3	0	0	1	0	1			33	6	1				
		Gull II	2500	3	1	1	0	0	0	1			16	2	1	1	0	0	0	1				16	4	1				
		Gull III	1500	3	2	3	0	3					24	2	0	3	0	2	1					24	6	1	1			
		Lark	1400	20	17	5	6	4	1				173	13	15	6	3	5	1	1				173	35	9				
		Petrel I	1700	8	7	3	2	2					62	7	3	4	4	2						62	18	2				
		Petrel II	1600	6	10	3	1	1	0	1			22	5	10	1	1	0	0	2				22	17	1	1			
	700 mb	Buz Delta	1300	3	6	2	2	2					125	0	7	2	2	2						125	11	2				
		Loon	900	19	20	14	7	6					56	4	10	6	7	11	0	1				56	20	14	2	3		
		Ptarmigan	900	23	17	13	7	3	0	1			33	10	12	11	5	6	1	1				33	32	10	4			
		Eagle	No icing																											
Fall	500 mb	Vulture I	1200	17	9	11	8	5	1	1	1		113	6	4	11	8	7	1	1	1			113	28	8	3			
		Buz Kilo	1300	25	42	24	13	16	7	4	2		96	8	15	14	11	23	7	5	4			96	55	20	10	2		
		Buz Delta	1400	15	15	12	10	7	8	0	4		111	12	7	7	10	8	6	2	5			111	44	12	1			
		Loon	1600	22	19	3	4	5	1				191	11	16	5	1	5	3					191	32	7	1	0	1	
		Ptarmigan	1300	5	7	2	3	1	1				236	1	6	2	2	2	1					236	10	3	1			
		Gull III	1500	2	5	2	0	1	1				17	1	3	2	0	0	1	1				17	5	3				
		Lark	1400	12	24	20	11	8	2	1			104	8	12	20	11	9	2	2				104	52	11	0	1		
		Petrel I	1700	19	8	10	6	5	2	1	1		43	7	4	4	2	5	5	1	2			43	16	9	3	1	1	
		Petrel II	1600	4	2	1	0	4	1	1			9	3	1	0	1	0	1	2	1			9	5	4				
	700 mb	Buz Delta	1300	18	27	13	7	7	1				96	6	12	12	7	8	4					96	30	14	5			
		Loon	900	27	27	14	4	2					46	8	17	8	6	5	1					46	24	15	5	0	1	
		Ptarmigan	900	14	12	7	4	3					42	8	11	3	4	4	1					42	24	5	2			
		Eagle	600	4	2								52	4	2									52	6					
Winter	500 mb	Vulture I	1200	10	13	11	11	5	2	0	0	1	122	5	8	9	5	4	3	3	0	1		122	25	12	0	1		
		Buz Kilo	1300	13	18	3	4	8	3	0	1		123	8	10	2	3	7	6	0	1			123	27	7	3			
		Buz Delta	1400	5	7	5	3	6	4	1			113	3	3	5	4	5	3	1	0	1		113	20	4	1			
		Loon	1500	10	13	7	2	3					188	4	5	4	2	5	1					188	12	6	2	0	1	
		Ptarmigan	1300	0	0	0	0	1					194	0	0	0	0	1						194	1					
		Gull I	1100	5	2	4	3	3					65	1	2	4	3	3						65	9	4				
		Lark	1400	31	55	15	12	6	2				110	13	27	17	10	13	3					110	56	19	6	1	1	
		Petrel I	1700	27	34	19	10	7	3	2	3		75	6	13	11	11	10	3	5	2	0	1	75	35	18	5	1	3	
		Petrel II	1600	6	17	4	1	5	1	2			29	5	5	5	3	4	2	1	0	0	1	29	17	8	1			
		Falcon	1300	0	0	3	1	1					21	0	0	3	1	1						21	5					
	700 mb	Buz Delta	1300	27	50	25	17	13	1	1	1		32	10	17	18	20	12	6	2	1	1		32	48	31	7	1		
		Loon	900	32	20	9	5	3					40	8	13	9	8	4						40	21	16	4	1		
		Ptarmigan	900	7	2	2	1						72	7	2	2	1							72	12					
		Gull I	700	4	3	3	2	5	0	1	1		78	3	3	3	2	5	0	1	1			78	17	1				
		Eagle	600	7	4	2							30	4	4	2								30	7	3				
	1500 ft	Lark	1400	3	2								151	1	3									151	3	1				
		Falcon	1300	1	4	1	1	2	1				12	0	2	1	2	2	1					12	6	2				

TABLE V. - CONCLUDED. FREQUENCY AND EXTENT OF ICING ENCOUNTERS

(b) DERIVED STATISTICS

[Parentheses indicate uncertain values, due to small number of encounters.]

Season	Flight level	Track	Av. number of encounters per 1000 miles	Av. number of icing encounters per flight	Miles of icing per 100 miles flight	Length of encounter, nautical miles					Probability of at least -			
						Average	Lower quartile	Median quartile	Upper quartile	90th Percentile	One encounter in 1000 nautical miles	One encounter in 2000 nautical miles	Two encounters in 1000 nautical miles	Two encounters in 2000 nautical miles
Spring	500 mb	Vulture	0.493	0.591	4.63	93	35	65	125	210	0.36	0.60	0.11	0.28
		Buz Kilo	.370	.481	3.88	105	35	75	150	240	.28	.49	.07	.19
		Buz Delta	.193	.271	1.81	94	30	65	120	230	.16	.29	.03	.07
		Loon	.080	.113	.50	63	25	45	90	140	.07	.13	.01	.02
		Ptarmigan	.015	.020	.11	72	(20)	(50)	(120)	(200)	.01	.03	.00	.00
		Gull I	.233	.256	1.97	85	40	70	125	180	.19	.34	.04	.10
		Gull II	.114	.286	1.27	106	60	85	135	220	.10	.18	.01	.03
		Lark	.165	.231	1.08	65	20	40	85	160	.14	.26	.02	.06
		Petrel I	.253	.430	2.56	101	35	70	130	240	.20	.37	.04	.11
		Petrel II	.090	.144	.65	72	(30)	(50)	(100)	(170)	.08	.15	.01	.03
		Falcon	.057	.075	.25	43	(15)	(35)	(70)	(130)	.05	.10	.01	.01
	700 mb	Buz Delta	0.417	0.541	3.48	83	30	63	115	175	0.31	0.54	0.08	0.23
		Loon	.843	.760	3.52	42	20	35	65	100	.54	.81	.23	.50
		Ptarmigan	.161	.145	.70	44	20	30	60	120	.13	.25	.02	.05
		Gull I	.165	.116	1.32	80	(20)	(50)	(140)	(300)	.14	.26	.02	.06
		Eagle	.320	.190	2.65	80	35	60	100	170	.25	.44	.05	.15
	1500 ft	Falcon	0.240	0.313	1.66	69	20	55	100	160	0.19	0.35	0.04	0.10
Summer	500 mb	Vulture I	0.475	0.570	3.50	74	20	45	105	180	0.35	0.59	0.10	0.27
		Buz Kilo	.648	.842	6.30	97	30	65	135	210	.44	.72	.16	.38
		Buz Delta	.510	.715	4.55	89	30	60	130	200	.37	.62	.11	.29
		Loon	.361	.528	2.18	60	20	45	80	130	.27	.48	.06	.18
		Ptarmigan	.225	.293	.99	44	20	35	55	85	.18	.33	.03	.09
		Gull I	.180	.200	2.57	140	(60)	(90)	(160)	(340)	.15	.28	.02	.07
		Gull II	.115	.290	1.12	97	(15)	(35)	(100)	(300)	.10	.18	.01	.03
		Gull III	.230	.346	2.01	87	30	70	130	200	.18	.34	.03	.10
		Lark	.175	.245	1.12	64	20	45	95	150	.14	.27	.02	.06
		Petrel I	.158	.268	.94	59	20	50	90	150	.13	.25	.02	.05
		Petrel II	.336	.538	2.42	72	30	50	90	160	.26	.45	.06	.17
	700 mb	Buz Delta	0.084	0.109	0.63	75	35	55	100	170	0.07	0.14	0.01	0.02
		Loon	.775	.697	5.42	70	30	55	100	150	.51	.79	.21	.46
		Ptarmigan	.896	.807	5.85	65	20	50	90	140	.56	.83	.25	.53
Fall	500 mb	Vulture I	0.290	0.348	2.54	88	20	60	120	190	0.23	0.41	0.05	0.13
		Buz Kilo	.560	.728	5.81	104	40	70	130	240	.40	.66	.13	.32
		Buz Delta	.302	.423	3.91	129	40	90	180	290	.24	.42	.05	.14
		Loon	.150	.233	.97	64	20	40	80	170	.12	.23	.02	.05
		Ptarmigan	.059	.076	.43	74	25	50	100	160	.05	.10	.01	.01
		Gull III	.299	.448	2.72	91	40	60	110	240	.23	.42	.05	.14
		Lark	.331	.463	2.98	90	40	75	115	180	.26	.45	.06	.16
		Petrel I	.418	.712	3.91	93	25	65	120	210	.31	.54	.08	.23
		Petrel II	.460	.730	6.40	140	30	110	220	320	.34	.58	.10	.26
	700 mb	Buz Delta	0.387	0.503	2.88	75	30	55	100	160	0.29	0.51	0.07	0.21
		Loon	.906	.815	4.70	52	23	44	70	110	.57	.84	.25	.54
		Ptarmigan	.610	.548	3.96	65	25	50	90	140	.42	.70	.14	.35
		Eagle	.175	.105	.35	20	(10)	(20)	(40)	(70)	.14	.27	.02	.06
Winter	500 mb	Vulture I	0.276	0.331	2.81	102	40	80	130	200	0.22	0.39	0.04	0.12
		Buz Kilo	.240	.312	2.34	98	30	60	140	240	.19	.35	.04	.10
		Buz Delta	.161	.225	2.06	128	40	100	200	300	.13	.25	.02	.05
		Loon	.108	.168	.69	63	30	50	85	130	.09	.17	.01	.03
		Ptarmigan	.004	.005	.07	---	--	---	---	---	.00	.01	.00	.00
		Gull I	.197	.217	1.67	85	20	70	140	200	.16	.30	.03	.08
		Lark	.448	.627	2.79	62	30	45	80	130	.33	.56	.09	.25
		Petrel I	.450	.765	4.07	90	30	55	110	190	.33	.57	.09	.25
		Petrel II	.413	.660	4.15	100	40	60	130	240	.31	.53	.08	.22
		Falcon	.147	.192	1.77	120	(80)	(110)	(160)	(220)	.12	.23	.02	.05
	700 mb	Buz Delta	0.873	1.135	7.12	81	35	60	105	170	0.55	0.83	0.24	0.52
		Loon	.932	.839	4.62	50	20	35	70	110	.58	.84	.26	.55
		Ptarmigan	.159	.143	.64	40	15	30	60	110	.13	.25	.02	.05
		Gull I	.284	.198	3.70	130	40	105	195	320	.22	.40	.05	.13
		Eagle	.541	.325	2.00	37	15	30	55	85	.39	.64	.12	.31
	1500 ft	Lark	0.023	0.032	0.07	32	(15)	(25)	(45)	(70)	0.02	0.04	0.00	0.01
		Falcon	.383	.498	4.14	108	30	75	160	260	.29	.50	.07	.20

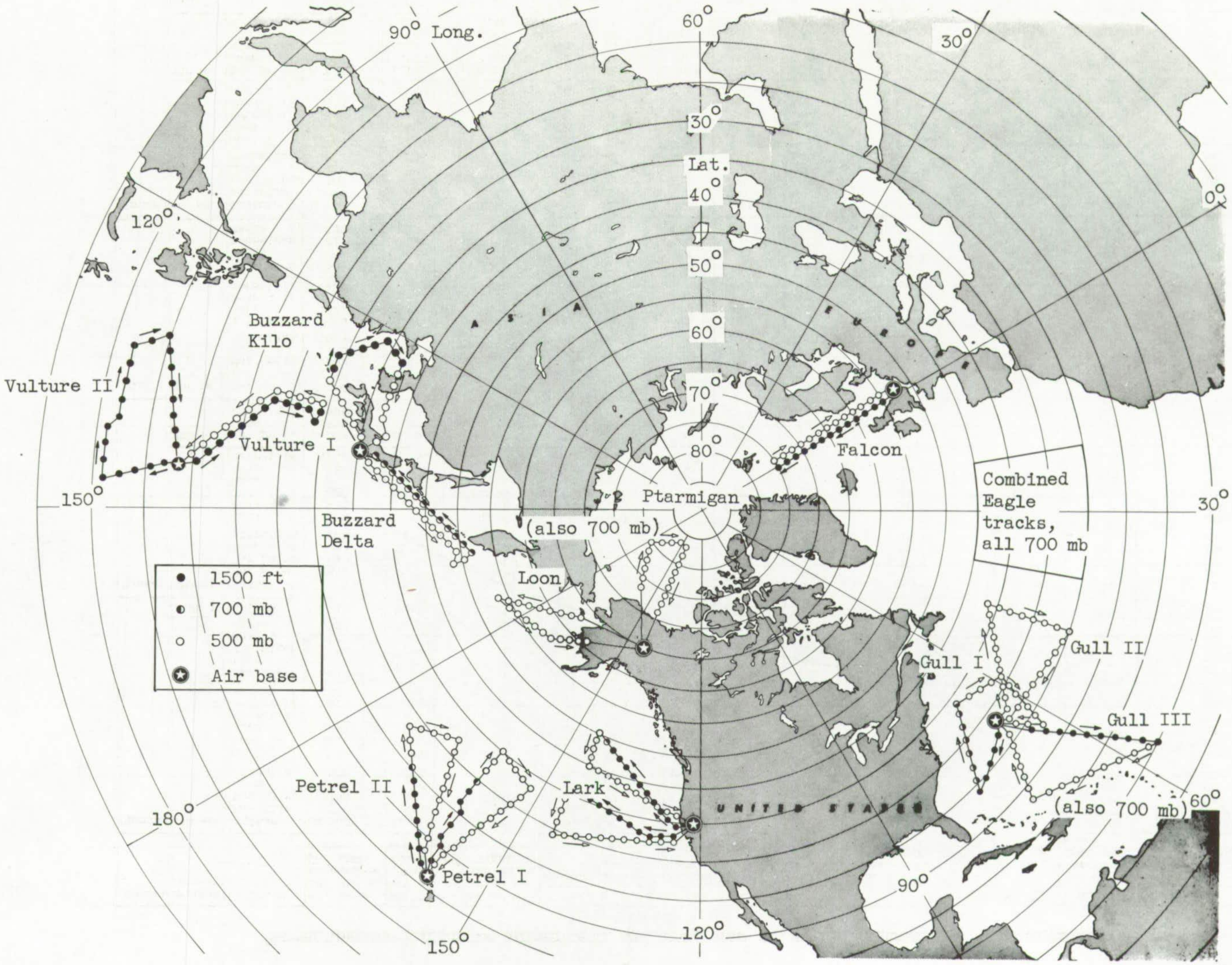


Figure 1. - Location and altitude levels of reconnaissance flights used to obtain icing statistics.

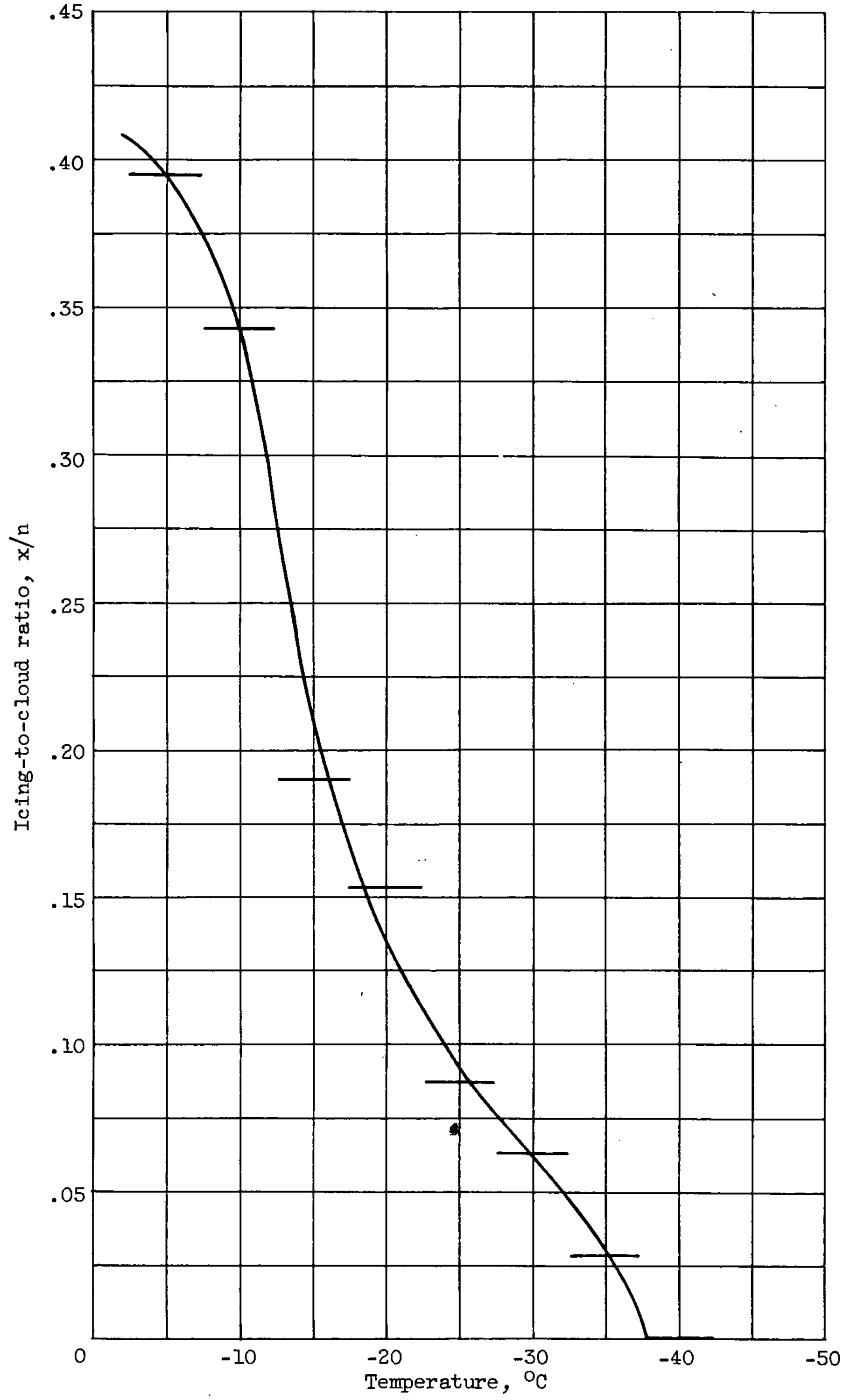


Figure 2. - Average relation of icing-to-cloud ratio to temperature.

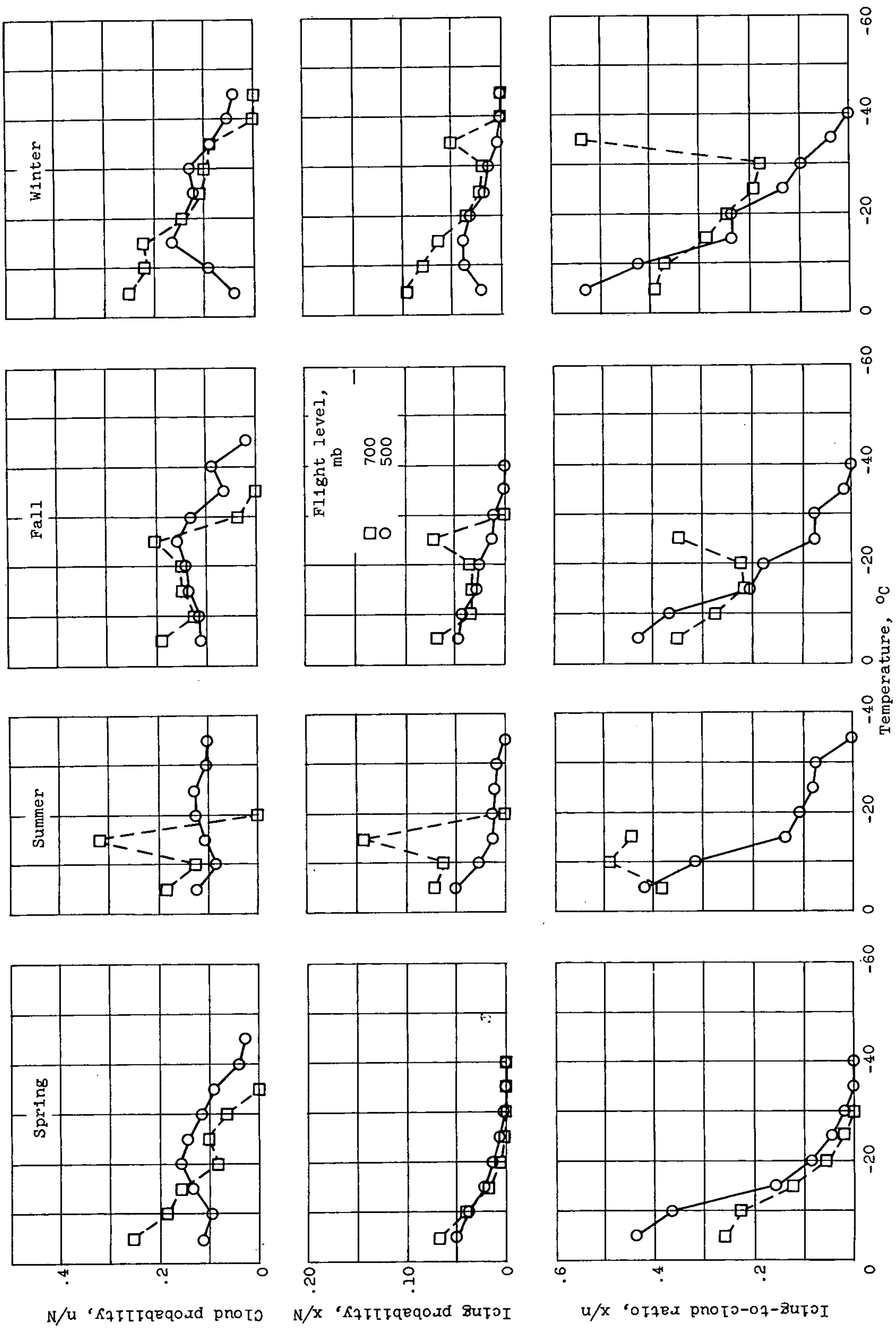


Figure 3. - Over-all seasonal and altitude effects on relation of temperature to cloud and icing probabilities and to icing-to-cloud ratio.

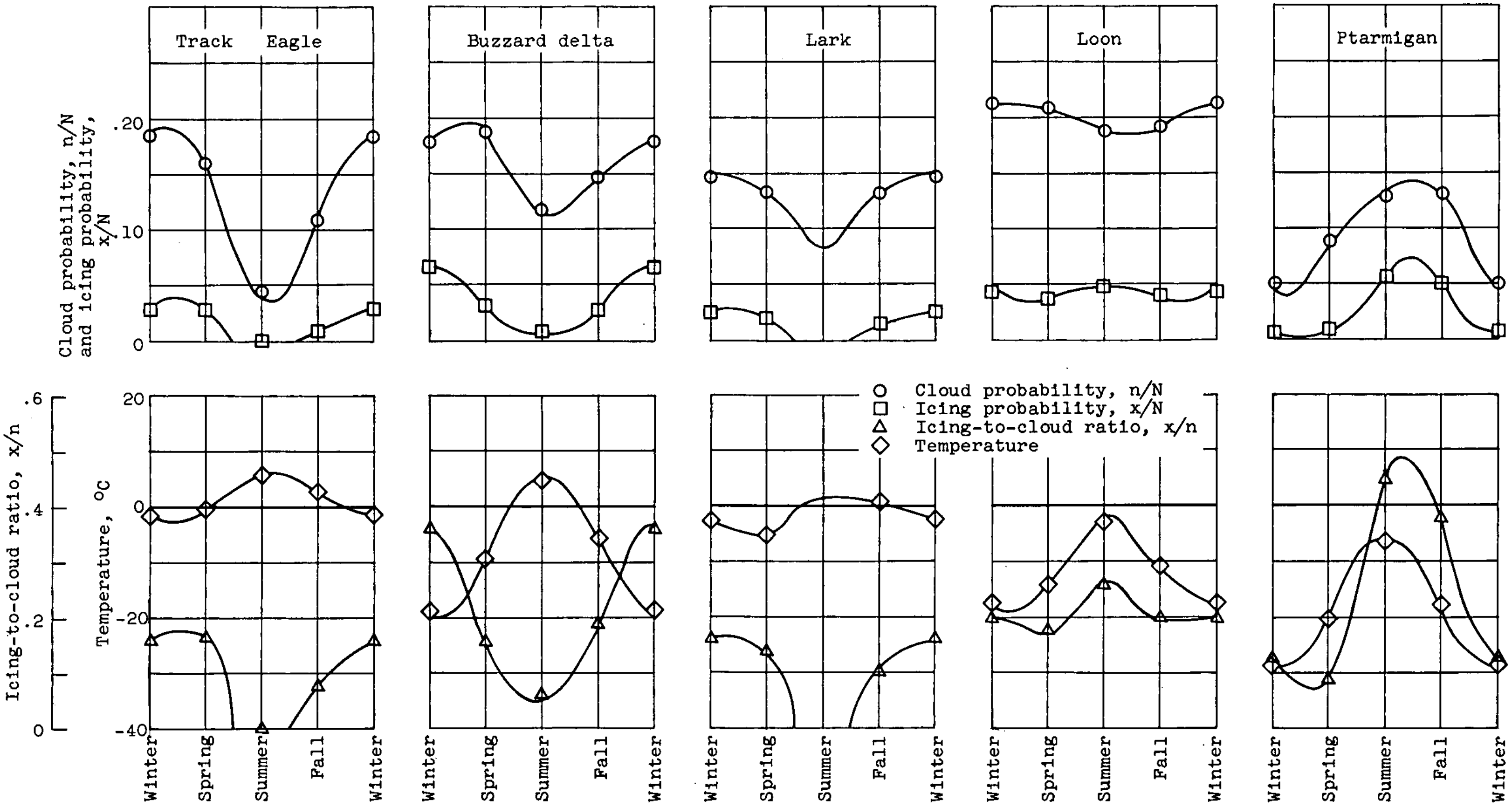
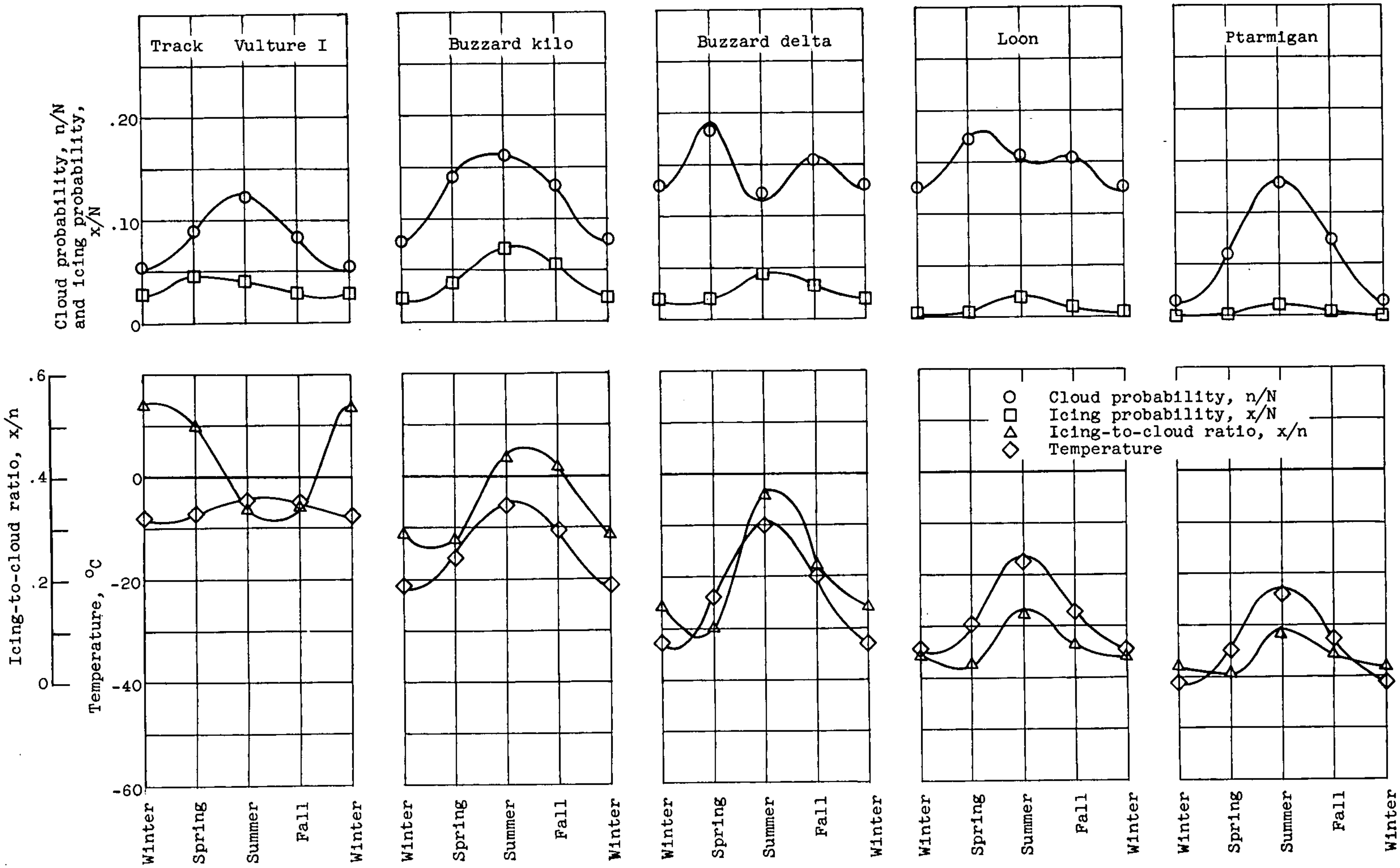
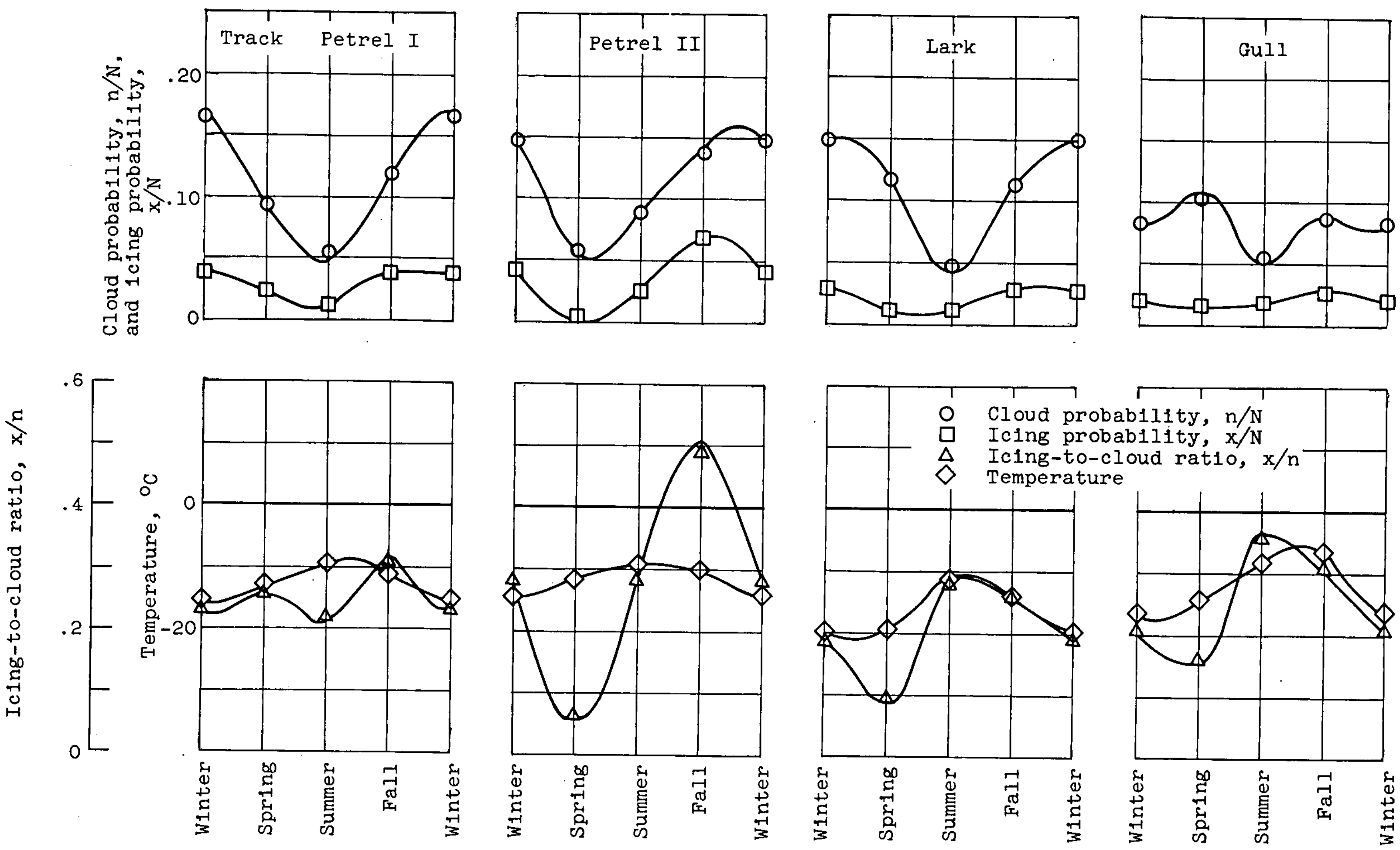


Figure 4. - Seasonal variations of cloud and icing probabilities, icing-to-cloud ratios, and average temperatures at 700 millibars.



(a) Group A; maximum icing in summer, maximum cloudiness in spring or summer.

Figure 5. - Seasonal variations of cloud and icing probabilities, icing-to-cloud ratios, and average temperatures at 500 millibars.



(b) Group B; maximum icing in fall, maximum cloudiness in winter or spring.

Figure 5. - Concluded. Seasonal variations of cloud and icing probabilities, icing-to-cloud ratios, and average temperatures at 500 millibars.

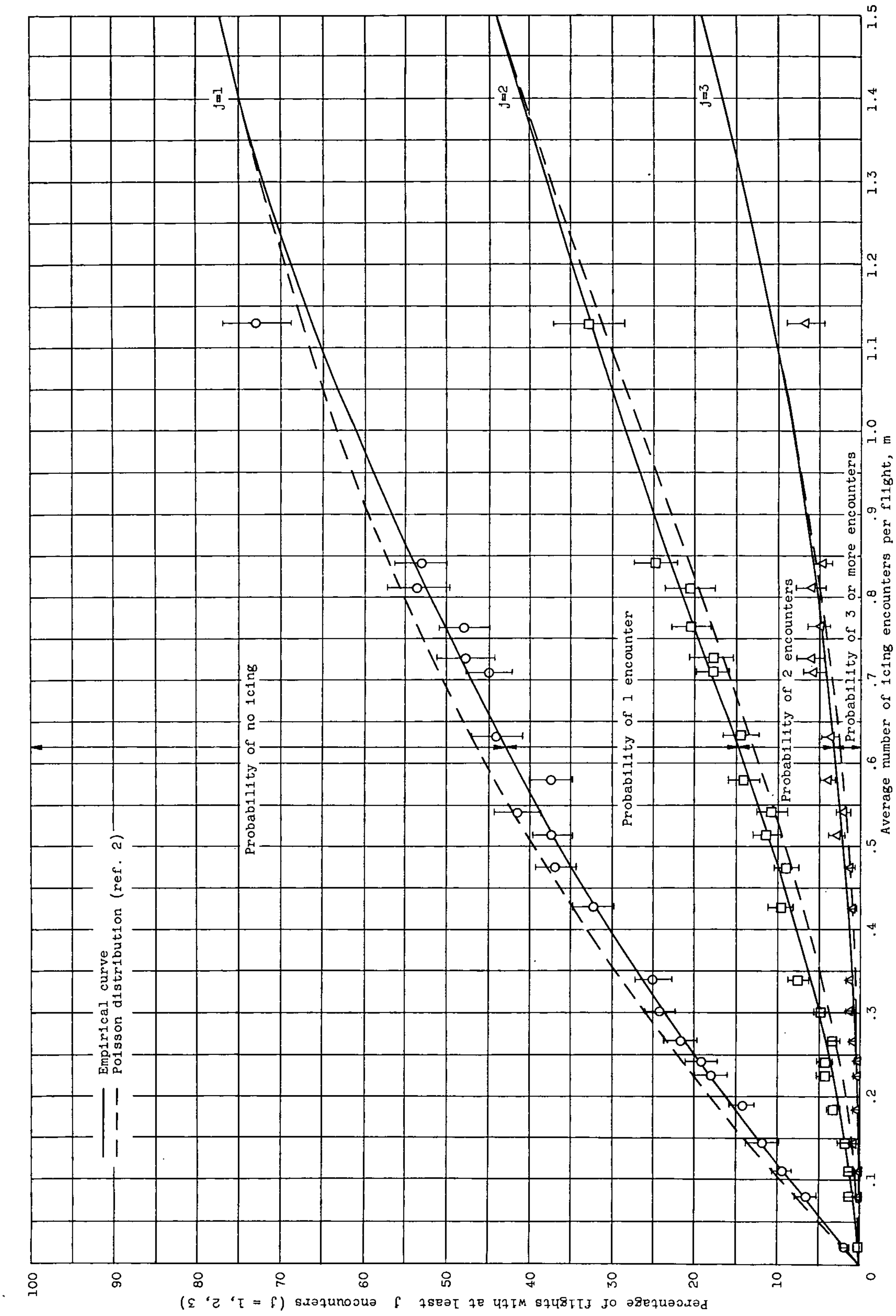


Figure 6. - Probability of various numbers of icing encounters.

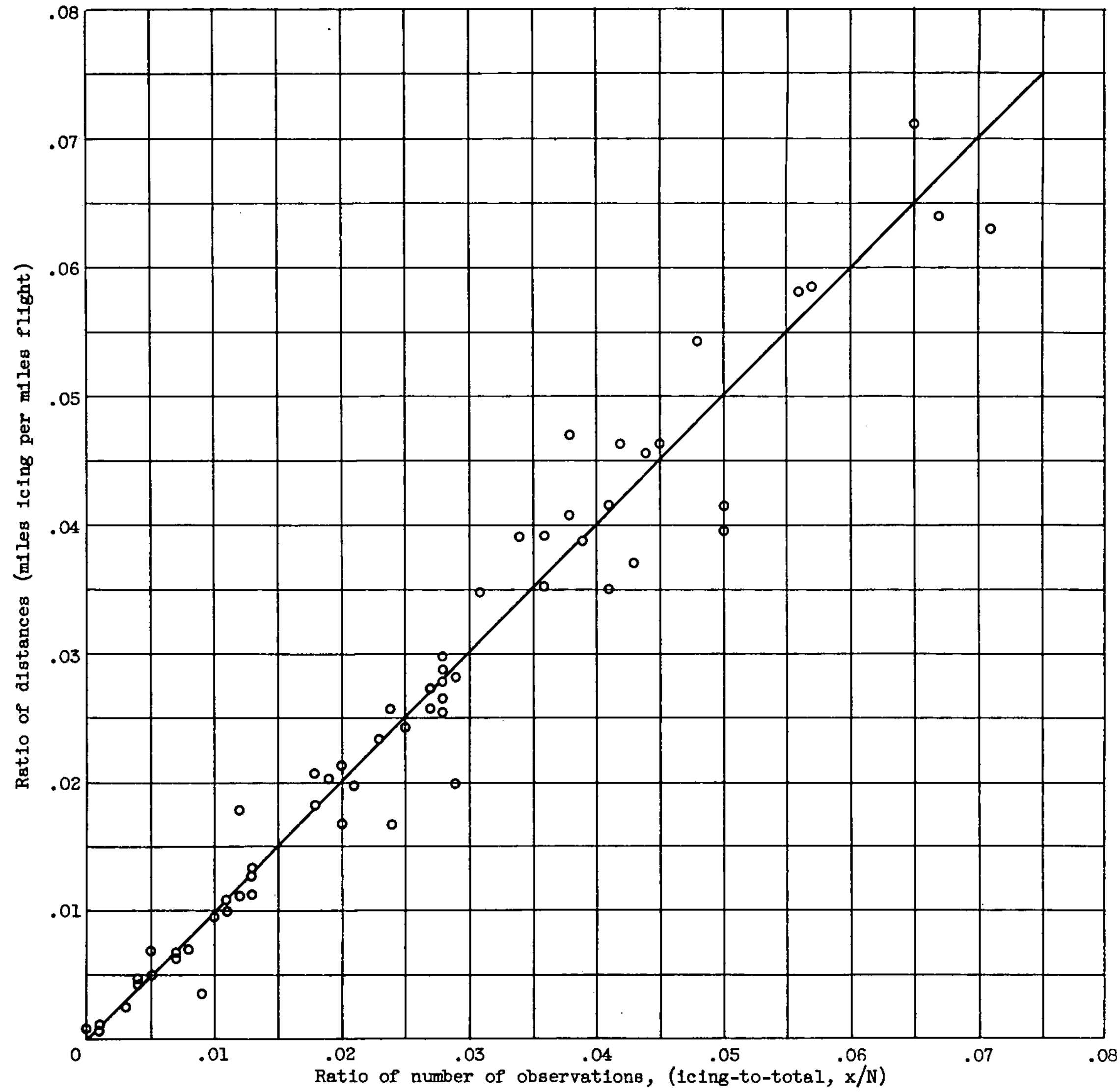


Figure 7. - Comparison of two estimates of probability of icing.

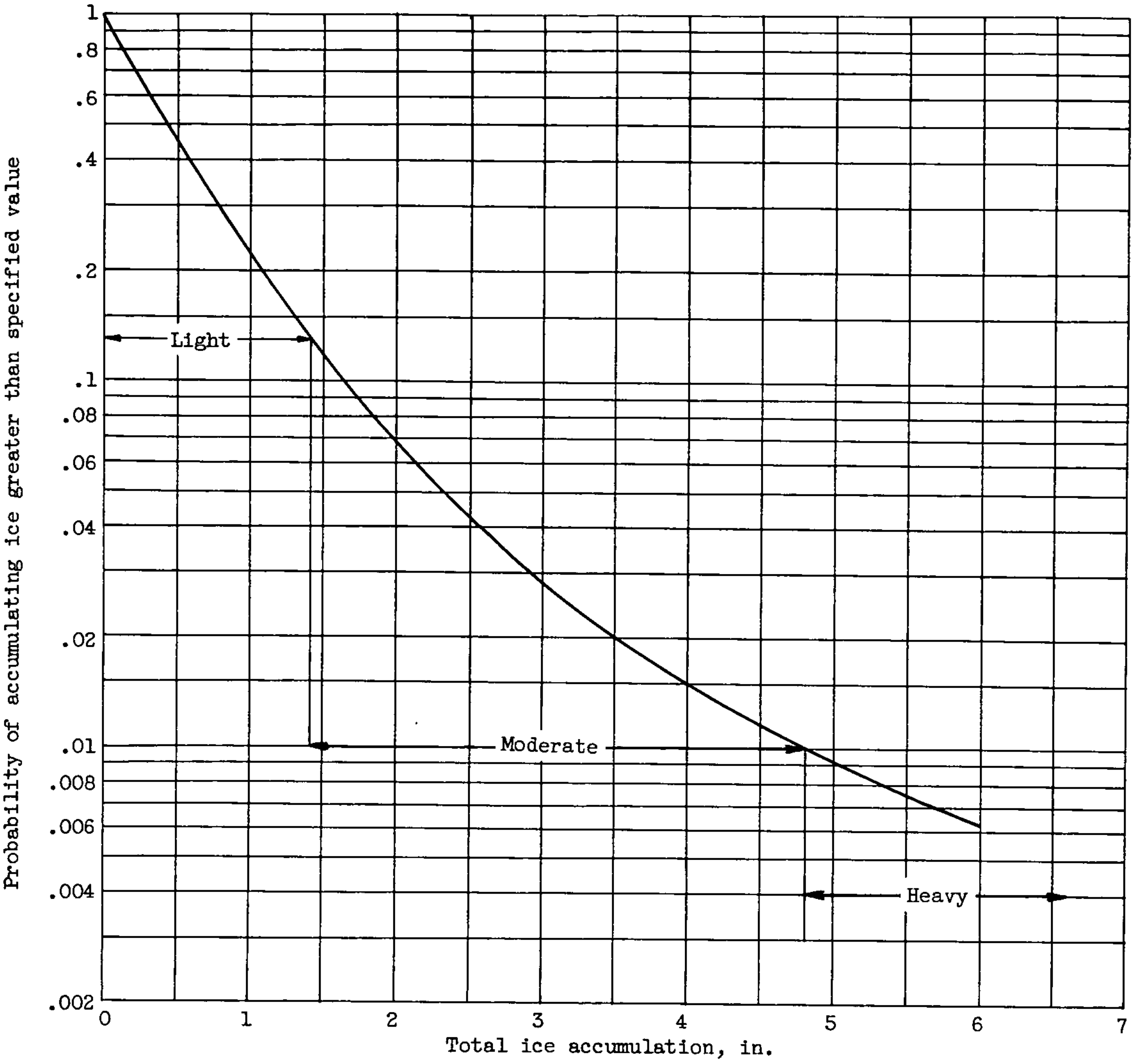


Figure 8. - Range of light, moderate, and heavy icing intensities, based on probabilities of total ice accretion measured on domestic air routes.