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THE FORMATION OF ICE UPON AIRPLANES IN FLIGHT

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Summary

This report describes the atmospheric conditions under which ice is deposited upon the exposed parts of airplanes in flight. It identifies the formation which is found under different conditions, and describes some studies of preventative means together with recommendations for avoiding the consequences of the formation.

Introduction

This study of the phenomena of the formation of ice upon the wings and exposed parts of an airplane while flying was prompted by the numerous reports of experiences in which airplanes were forced to be landed on account of the deposit of quantities of ice upon the structure. From these reports it was concluded that the failure of many long-distance flights through cold regions, regarding the fate of whose personnel nothing has been learned, may possibly have been due to the formation of ice on these airplanes, which prevented them from continuing to their destinations.

Reports were obtained from every available source where these phenomena were reported to have been observed. Much of the information was contradictory, the formation being reported as having occurred under a wide variety of conditions usually where moisture exists, either in the form of fog, clouds, or rain, but at temperatures varying from 32°F. to as low as -14°F.

Methods and Apparatus

The lack of agreement as to the conditions under which a deposit of ice might be expected indicated the necessity for a connected study at first hand. Some difficulty was anticipated in locating the necessary conditions for this study and the suggestion was made that it might be necessary to equip an expedition to travel in those northern parts of the continent where the proper conditions might occur most frequently. However, the idea was formed at this laboratory that the conditions might be found at Langley Field by flying to an altitude where freezing temperatures would be met, accompanied by the presence of rain, clouds, or a rising fog bank.

An airplane was equipped with external air temperature thermometers, of the N.A.C.A. electric type and, in addition, some convenient forms and surfaces were fitted, upon which the formation of ice might be studied, as well as upon the structure of the airplane itself (Fig. 1). This airplane was kept in constant readiness and at such times as suitable conditions appeared probable, flights were made, during which observations and notes were taken.

It was somewhat discouraging to find that repeated efforts to photograph the formation of the ice while in flight were fruitless, and that, excepting on a few occasions, the descent to warmer atmosphere resulted in the melting of much of the formation which, if not entirely melted off, was shaken loose in the jar of landing. However, on certain occasions when the ground temperature was near freezing, landings were made with the formation intact and photographs and further observations could be made on the ground, in addition to the observations in flight, which were made in every case.

Results

The results of a great number of observations have clearly identified the conditions which must prevail in order that ice may be deposited upon the airplane. First, moisture must be present in the atmosphere, whether in the form of fog, clouds or rain; makes little difference, excepting, as would be expected, in the rapidity with which the deposit forms, that is, the more free water, the more ice in a given time. Measured observations of the relative humidity were not made in flight and were not considered of importance.

Secondly, low temperature must exist, that is, 32°F. or less. The range of a few degrees below 32 F. is a zone of temperature in which a coating of transparent, solid ice will form, very similar to the formation which is observed on trees in what is generally called a "sleet" storm. The exact range of temperature in which this will occur is not definitely established and the width of the zone is dependent on the presence or absence of certain conditions, i.e., temperature inversion, and sub-cooled droplets, which permit water to exist in its liquid state at a temperature lower than 32°F. These will be discussed later.

The formation of ice under these conditions is illustrated by Figure 2, which shows the tendency of the formation as observed in a number of actual cases during the experiments at Langley Field. It will be noted that ice in this form has a definite tendency to mushroom or to enlarge its frontal area at the very front of the formation.

An important observation which has been frequently confirmed is illustrated in Figure 3. At temperatures below the zone directly below 32°F., that is, at temperatures as low as 15°F., which is definitely beyond the first zone, though not necessarily near its lower boundary, an entirely different type of formation is noted, there being practically no tendency to mushroom as in the case in the zone immediately below 32°F. Further, the texture and appearance of the ice so formed is radically different, and is known to meteorologists as "rime" ice. In the conditions at or near 32°F., as was said above, the ice is clear and hard. In this latter case the formation is pure white, opaque, and granular in texture. It is, in fact, snow of very fine flake size or more truly, since it lacks flake design, a collection of tiny ice pellets, which have but little cohesion or adhesion.

The formation of either the clear ice or rime ice upon an airplane produces danger from two sources: the first, which is the lesser, being the additional weight to be carried by the airplane due to the deposit, and the second and more serious, the loss in lift and increase in drag resulting from the irregularity of the shape of the formation. In Figure 2, it will be noted that an irregular shape is developed due to the ice formation, which is ruinous to the aerodynamic efficiency of the airfoils or struts upon which it is deposited. The irregularity, where it exists, is found near the leading edge of the airfoil or strut. Here the normal air flow is most critical and the malformation, therefore, has the maximum of detrimental effect. In Figure 3 it is noted that the deposit, rime ice, is of such form that little or no aerodynamic effect would be expected on the form upon which it was deposited.

It is, of course, apparent that the clear ice is heavier per unit volume than the snow-like deposit, but of itself the matter of increased weight requires little comment if it were not for the fact that in conjunction with the reduced aerodynamic efficiency the increased weight renders the conditions more dangerous. As for the weight itself, it is believed that the weight of deposit would not be much more than the weight of the fuel which was consumed in the flight, before and during the deposit. These, of course, cancel.

The ice formation has been charged in numerous instances with clogging air-speed-heads and other exposed instruments, and there are some reports of jammed controls. It is quite obvious that the formation upon the Pitot or Venturi head of an air-speed meter or other instrument would interfere with its operation. However, the jamming of controls has not been experienced in the experiments at this laboratory. It is thought that the reported instances of jamming have occurred on older and obsolete types of airplanes whose control systems were more exposed, and that it is much less likely to occur upon the more modern airplanes.

During the conduct of these experiments several unusual cases of temperature inversion were noted, the most unusual being illustrated by Figure 4. On this day, the ground temperature was 35°F. At 600 to 800 feet, it was 31°F; at 3000 feet, it was 38°F, and this temperature was constant to an altitude of 7500 feet. There was a fine rain at the ground level which extended to an altitude of about 4000 feet, with very heavy snow between that altitude and the maximum altitude reached, about 7500 feet. Figures 5 and 6 illustrate a formation which was obtained upon this flight. No deposit of any form whatsoever was observed at any other altitude or condition other than at from 600 to 800 feet altitude in a fine rain which froze immediately upon striking the airplane. It is also interesting to note that the area of low temperature, 31°F, extended laterally through an area of not more than half a mile square at that altitude, and that this area was almost entirely over the water of the river in the vicinity of Langley Field. Temperature inversion which permits rain to fall from a higher and warmer air into a lower, colder stratum need not necessarily be considered an exception to the rule. When in the conditions of rain, clouds, or fog, this inversion may be expected as a matter of more frequent occurrence.

The mushrooming of the front edge of the ice formation may be explained as follows: The suspended particles of water, as in a light rain or fog, have an internal pressure developed by the surface tension of the drop of sufficient magnitude to lower the freezing point, thus permitting water in these drops to remain in the liquid state, although at a temperature of 32°F or less. It is thus evident that the surface tension being broken as the drop strikes the airplane, the freezing, while not instantaneous, is more rapid than in the condition of heavy rain in moderate freezing temperatures.

Figures 8, 9, and 10 illustrate a formation at lower temperatures. The flight which resulted in the deposit shown in the photographs was made at an altitude of about 800 feet, the temperature being from 12°F to 15°F. On this day a heavy ground fog existed at a ground temperature very close to freezing. This had just begun to rise when the flight was made, and twenty-five minutes of flight through this fog or low cloud bank resulted in an accumulation as shown. In this case it is quite evident that the cloud bank or fog consisted of suspended ice particles and that the formation upon the structure is substantially miniature snowdrifts.

Summarizing the experiences which have been considered in the preparation of this report, whether from the first-hand information of the experiments made at Langley Field or from the many reports received from American pilots and operators, it may be said that the formation of clear ice is limited to the range directly below 32°F, this range being probably of not more than a few degrees. The condition called snow ice, or rime, is encountered in temperatures below this range, possibly extending as low as 14°F or below, which is reported, but not within the experience of the experimental work. The lowest temperature accompanied by any formation met with in the work was approximately 0°F.

Methods of Prevention

A means of prevention of this formation in any form is most desirable and many suggestions have been made. The field of possible means of prevention has been very completely covered, but the most frequently suggested and obviously practical methods have been along three principal lines: first, to heat all or part of the wing; secondly, to apply a coating of an oily nature; and thirdly, to apply a substance which would unite with water and provide a solution having a lower freezing point. The oily surfacing seemed to present the most promise and several attempts were made to prevent the formation by coating one-half of the small metal airfoil which had been placed in a convenient position on the airplane with a substance of this nature. Oil, grease, wax, and paraffin were among the substances employed. The unexpected fact, developed in the flight experiments, was that in each case ice was observed to form upon the treated surface more quickly than upon the bare metal. At first thought, this appeared very unusual behavior, but it should be remembered that the drops of water are bombarding the frontal area of the greased surface at flight velocities approximating 100 m.p.h., quite unlike the behavior of water which is simply poured upon such surfaces. These drops strike the oily or greasy material and are, to a certain extent, embedded therein and held, so that they freeze before they have had an opportunity to roll off.

A further study of the accumulation of ice and of means for preventing it is being conducted in a specially constructed wind tunnel, in which the humidity and temperature of the air stream are controlled so as to promote the formation of ice upon model structures placed in the tunnel. The results of this more exhaustive study will be presented separately, but it may be remarked that confirmation has already been obtained of the flight observations in regard to the accumulation of ice on oily or greasy surfaces.

The proposal to heat the wing is obviously limited to such methods of heating as would be practicable, and the piping of the exhaust from the engine through the leading edges of the wings seems the most practical possibility. The results of experiment along this line have shown that the heated leading edge will prevent the formation of ice at that location, but that the formation may be expected farther back along the chord of the wing in only slightly diminishing quantity.

The broadest possibility lies in the soluble coating field. Salt and several chemicals have been so applied, as has simple sugar syrup, which latter, incidentally, has shown excellent results. It must be evident, however, that any such material so placed upon the surfaces of the airplane will, in any protracted period of flight through ice-forming atmospheric conditions, be removed by the "scrubbing" action of the water striking the surfaces at the high speeds of flight.

Conclusions

Ice, in the true sense, will only form in a zone of temperatures of unknown, but narrow, width below 32°F when clouds, fog, or rain are encountered. The ice formation so deposited will assume an irregular contour upon the wing or part of the airplane. This irregular shaped mass of ice, when applied to an aerodynamic form, produces a malformation extremely detrimental to its efficiency. This malformation, in conjunction with the added weight of the ice, may be expected to necessitate discontinuance of flight.

In temperatures below the zone in which clear ice is formed an entirely different formation is deposited. This is a formation more similar to snow. Its contours do not produce the detrimental aerodynamical features of clear ice and its weight is less.

Temperature inversion may interfere in any case.

Recommendations

There appears little likelihood of successful prevention of the formation of ice on the airplane in flight by the application of any preventative means. However, it appears possible to avoid the conditions in which it is formed and thus escape the dangers it would produce.

The formation of clear ice is found only in a restricted range of temperature just below 32°F, and the successful avoidance of the conditions for ice formation by avoiding the area in which the conditions of temperature and moisture are conducive to the formation need not place too great a limitation on the operation of the airplane. If pilots can be well and thoroughly acquainted with the conditions controlling the formation of ice and particularly if they can learn that every deposit upon the wings or parts of an airplane is not necessarily hazardous, the problem will be in a large measure solved.

They must know that clear ice, which forms in a narrow range of temperature just below 32°F, is almost certain to be deposited, if the conditions favorable to its deposit are maintained sufficiently long, and that this formation is detrimental to the aerodynamic efficiency of the wing or other part. They must, therefore, learn as a matter of practice, to avoid this accumulation of ice. This avoidance is not difficult since it will not occur except in the presence of moisture in reasonable quantity, which should be clearly evident, visually, whether the moisture be in the form of rain, fog, or clouds. The temperature range is definitely limited to a few degrees below 32°F. A distance type thermometer should be so installed as to apprise the pilot, by means of a thermometer dial upon his instrument board, of the temperature taken at a remote point on the airplane and showing the temperature of the air through which he is flying.

On the other hand, all deposits of an icy nature are not dangerous, and those which form at lower temperatures than in the zone immediately below 32°F, and which are readily identifiable by their pure white color, will not necessarily produce a malformation of the aerodynamic forms. In either case, the weight, while appreciable, does not introduce a great hazard, excepting in connection with the reduced aerodynamic efficiency caused by the malformation of profiles when such malformation occurs. Safety, therefore, obviously lies in avoidance, and while temperature inversion may always be expected to complicate the situation, a selection of temperature by a change of altitude should tend to eliminate the hazard.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 21, 1929.

Fig.7 The formation of ice on a propeller in flight.
Conditions same as in Fig.5.

Fig.10 Formation of rime ice on streamline wires in flight.
Conditions same as in Fig.8. Note pure white color. The dangerous condition of ice formation around 32-30° F does not have this color and does not form quickly on stream line wires. This rime ice condition is not dangerous.

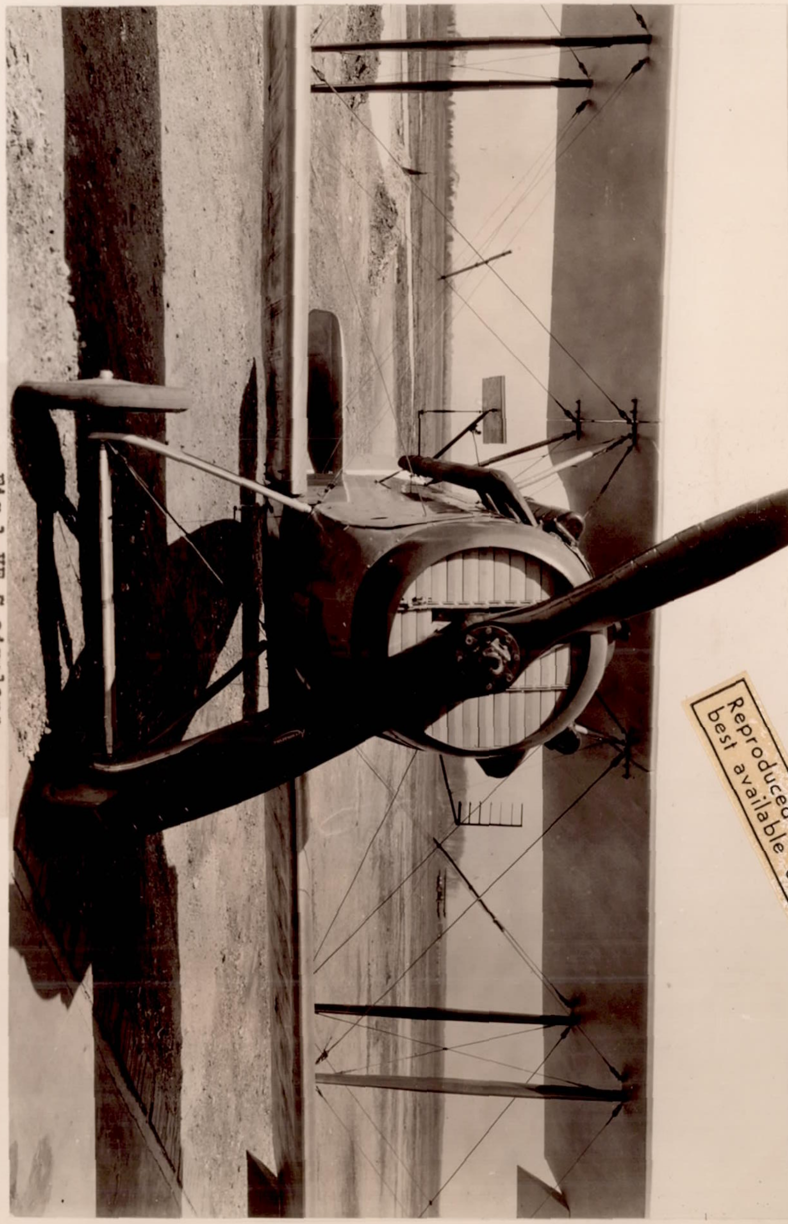
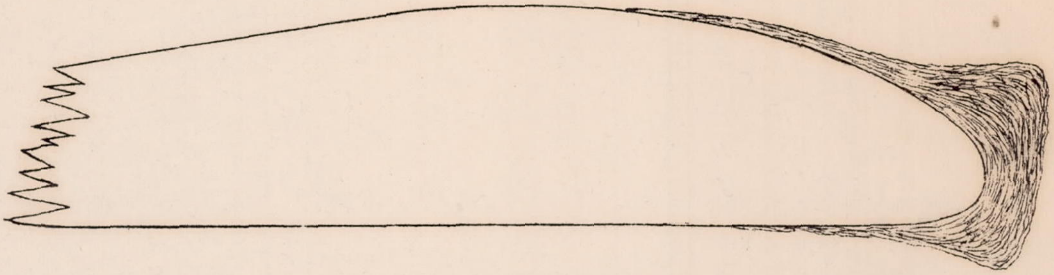
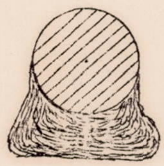


Fig.1 VE-7 airplane.

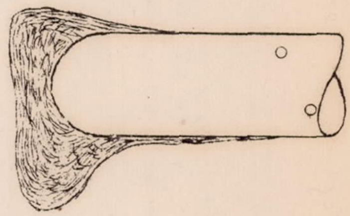


Formation of ice on leading edge of wing.

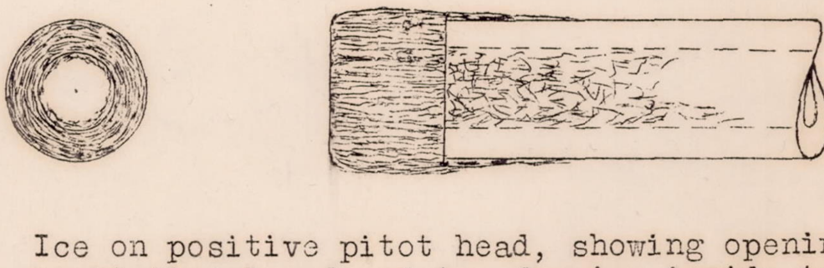
Ice on streamline wire. (Very slow to form if at all.)



Ice on round wire.

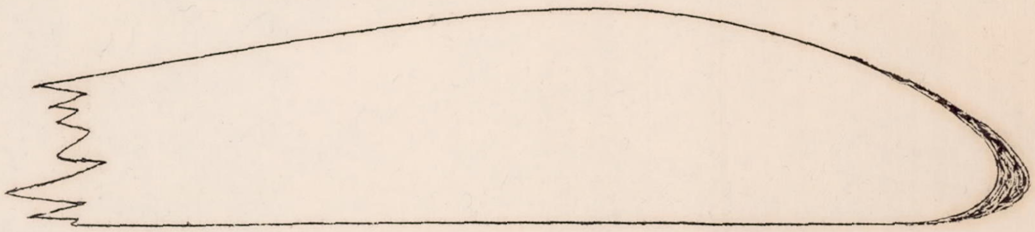


Ice on end of rounded batten.



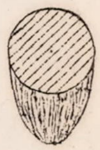
Ice on positive pitot head, showing opening partially closed and ice forming inside tube.

Fig.2 Sketches of ice formation on wings and wires. (From notes and sketches made on numerous flights.)

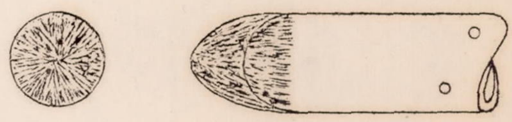


Formation of rime ice on leading edge of wing.

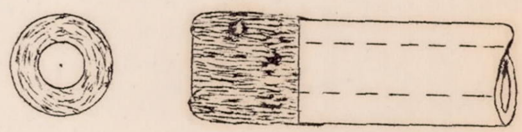
Formation on stream-line wire. (Forms very quickly and on all occasions.)



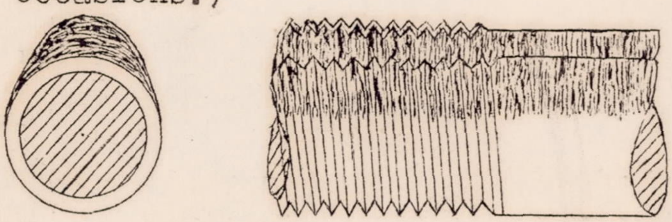
Formation on round wire.



Formation on end of negative pitot head.



Formation on end of positive pitot head, showing interior of tube clear.



Formation on threaded end of streamline wire, note ice following contour of threads.

Fig.3 Sketches of ice formation on wings and wires. (From sketches and notes in flight.)

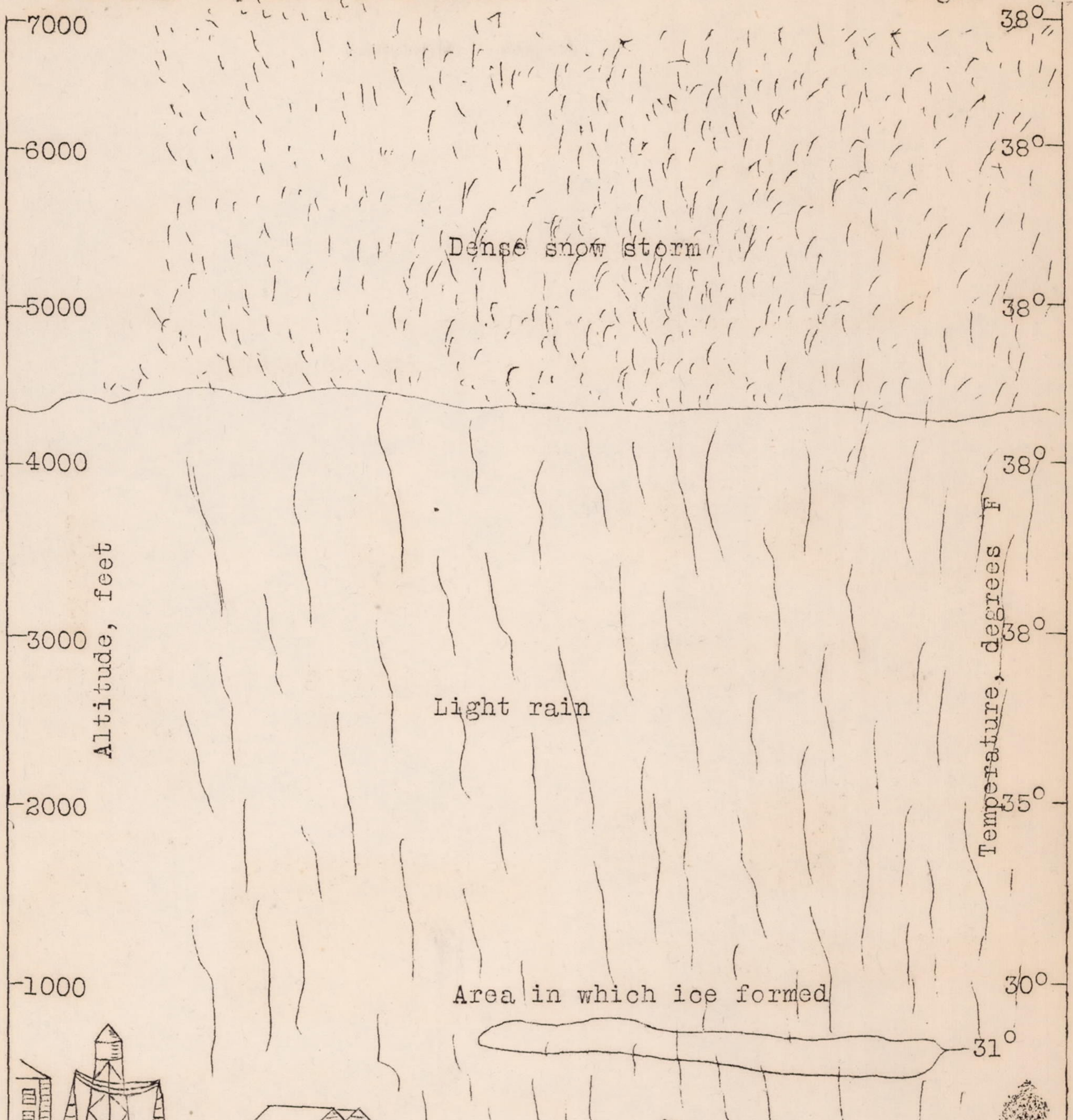


Fig.4 Illustrating a condition of temperature inversion encountered during tests.

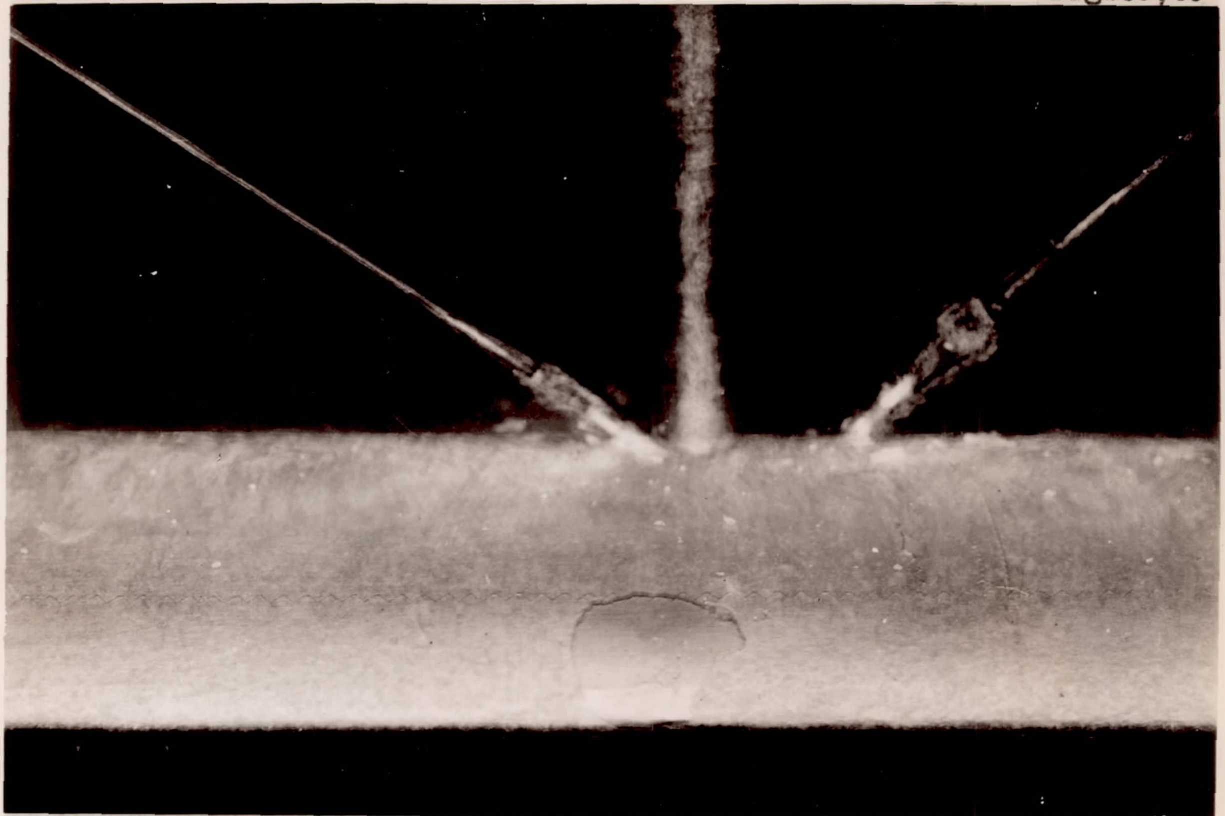


Fig.5 Ice formation on wing of VE-7 airplane at 31° F. The deposit was accumulated during a twenty minute flight through light rain at altitude of 600-800 feet. Approximate thickness of ice, 3/16 inch.

Fig.6 Ice formation on wing of VE-7 airplane at 31° F. Same as Fig.5, end view.

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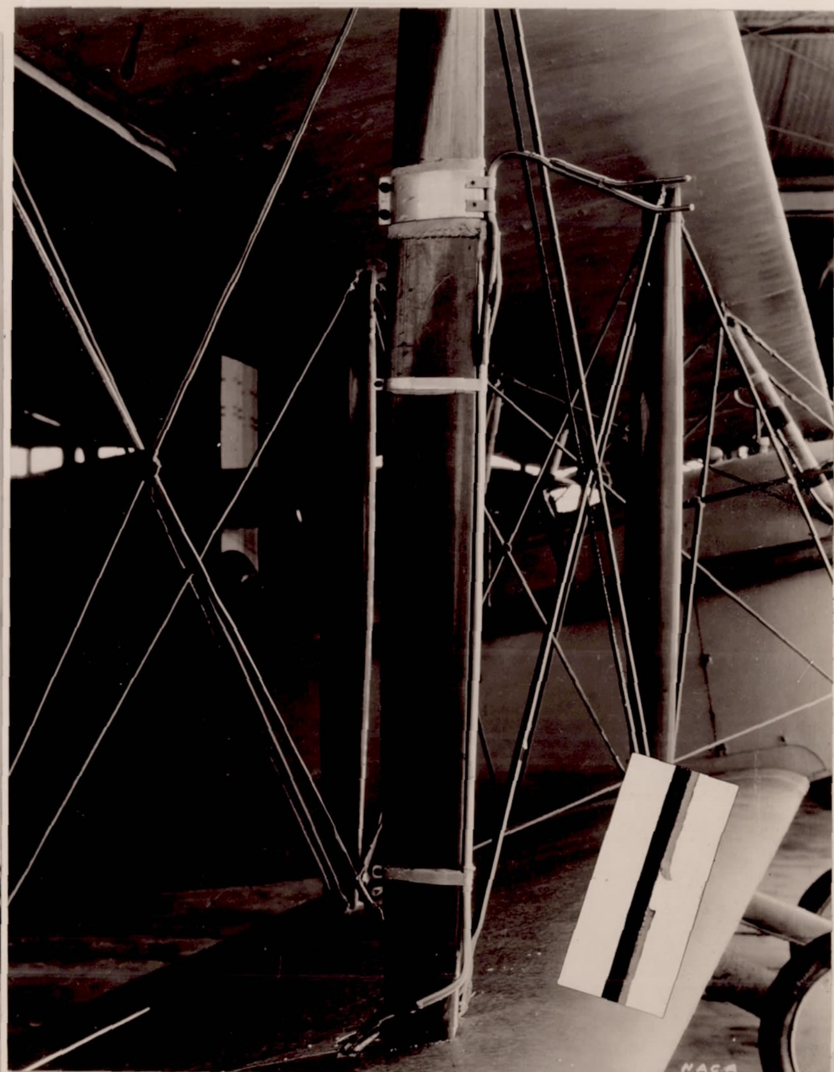

Fig.8 Rime ice deposit on airplane in flight, temp. 12-15° F. Note pure white deposit on all wires and tips of air speed head. Deposit accumulated in flight of 25 minutes in heavy fog at altitude of 800 ft. Temp.12-15°F.

Fig.9 Formation of rime ice on struts and wires in flight. Conditions same as in Fig.8. Note deposit follows contours of wire terminals, see Fig.3.

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