FILE COPY
NO. 2

FILE COPY
NO. 1-W

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

CASE FILE
COPY

No. 293

THE FORMATION OF ICE UPON EXPOSED PARTS OF AN AIRPLANE IN FLIGHT

By Thomas Carroll and Wm. H. McAvoy
Langley Memorial Aeronautical Laboratory

Washington
July, 1928

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 293.

THE FORMATION OF ICE UPON EXPOSED PARTS OF AN AIRPLANE IN FLIGHT.

By Thomas Carroll and Wm. H. McAvoy.

The formation of ice upon the wings and other exposed parts of an airplane in flight has presented a hazard which has long been appreciated. Experiences which have been encountered during the last year have focused the attention of the aeronautical world upon it and have brought forward a demand for more definite knowledge as to the character, the causes, and the possible means of prevention of this hazard.

The National Advisory Committee for Aeronautics, at the request of the Army and Navy, is coordinating and gathering all the information in regard to actual accidental experiences and further, has with some success, sought and examined the phenomena experimentally.

Information which has been obtained from a large number of pilots who have encountered this ice formation identifies the conditions as follows: A condition of high humidity, usually heavy fog which, more often in the form of clouds, either broken cumulus clouds, strata formation, or a condition of actual rain, must be encountered at a temperature not more than a degree or two below the freezing point, 32°F. The formation of ice has been reported by some at temperatures considerably below 32°F, but these reports in view of a preponderance of evidence as well as definite experimental data, appear to be of a secondary condition which in formation and in consequence are considerably different from the condition encountered at, or near 32°.

These many reports which come in the greatest numbers from air mail pilots who by the nature of their work are forced into or through conditions similar to those described above, indicate that the DH-4 airplane, either on account of its more extensive use or possibly on account of a peculiar susceptibility to the conditions, has encountered the phenomena more often. The element of greater susceptibility appears to be confirmed by the first evidences of ice formation appearing upon round wires with which this airplane is equipped. The increase in frontal area and consequent increase in parasite resistance and the consequences thereof are discussed later.

When an airplane encounters rain or heavy fog at a temperature of 32°F. minus only one or two degrees, the conditions are ideal for the formation of ice. The ice forms rapidly and the continuation of its formation is dependent only upon the maintenance of the conditions, with an almost certain reduction in flying efficiency which eventuates in a forced landing within a period of time which is only dependent upon the prevalence of the conditions, probably in no case longer than one hour, while in other cases where the conditions of high water content of the air, a temperature just below freezing and an already overloaded condition of the airplane, a lapse of only fifteen or twenty minutes would be sufficient to force the airplane down.

A condition is possible, though probably less frequent, in which a warmer stratum of air is found at an altitude higher than that at which the airplane is flying and from which rain falls into a lower stratum of lower temperature, 32° or less, within which the airplane is flying. The consequences of these conditions are practically the same as in the other more general case.

It is generally reported that the formation of ice under the ideal conditions which are mentioned above appears first upon wires, the forward edge of struts and the leading edge of wings accompanied only slightly less frequently by similar formations on the leading edge of the propeller blades and upon the bosses of the propeller and finally upon the fuselage itself and the tail surfaces, although it is highly probable that the formation upon the tail surfaces is almost coincidental with that upon wings.

The amount of the formation appears to be entirely dependent upon the extent of the conditions necessary to form ice and the time in which they prevail. Reports vary in regard to this amount through a range of from a thin film to a thickness of three or four inches, the latter condition being considered somewhat exaggerated. Authentic and reasonable reports of up to three-quarters of an inch thickness on the leading edge of wings and struts are found and are felt to be the reasonable consequences of a reasonable length of time under the conditions as above set forth. The shapes of these formations are most generally reported as a shell or crown of ice formed at or near the entering edge and tapering off rapidly to no more than a relatively thin film accompanied in many cases by secondary formation of fringe-like icicles along the trailing edge of the wing. The general formation appears to be similar to that shown in Figure 1.

In order to experimentally study the conditions and their consequences, the National Advisory Committee for Aeronautics equipped an airplane with small auxiliary surfaces and aerodynamic shapes similar to struts, wires, Pitot heads, etc., for the study (Fig. 2). This airplane was flown to an altitude where a temperature of 32°F. was encountered, at such times as cloud formations could be found at the coincident altitude. Here it was discovered that ice formed rapidly in conformity with reported experiences, in regard to quantity, character, shape, and rapidity of formation.

An examination of this confirmatory data indicates that the weight of ice collected can very possibly be sufficient to force the airplane to rapidly lose altitude on account of the increased loads, but it is more readily evident that the malformation of the aerodynamic shapes may so increase the drag and reduce the lift as to produce a loss of altitude even greater in consequence, the combination of the two working in the same direction having a double effect.

The general shape of the deposit appears to be very similar to that illustrated in Figure 1, with a considerable roughening and ridged effect to the area in the last two-thirds of the wing chord along the upper surface. The formation on round and streamlined shapes is similar to that shown in Figure 3. It is also obvious that an airplane similar to the DH-4 which has high parasite resistance, is more susceptible to the conditions than would be a pure cantilever monoplane type in which parasite resistance is at a minimum, the increase being due to the malformation of the aerodynamic shapes of the parasite resistance as illustrated in Figure 3.

It is possible that angle of attack and flight speed may have some effect upon the rapidity with which ice forms. It appears, however, that this is small.

The loss of instrument operation due to clogging of air speed lines and the venturi of the bank and turn indicator, etc., with ice is a coincident, and serious hazard, since on account of the nature of the aerological conditions, instrument directed flight is necessary to maintain a course. The interference to the functioning of the control surfaces by freezing or clogging of control hinges or exposed pulleys is possible although no definite or considerable amount of evidence has been presented of this occurrence. It appears certain that the continuation of the flight would be impeded by the other causes before this interference in control would become important.

That ice may form upon the propeller while in flight is definitely established. This is substantiated by reliable reports, although it has not been observed in the experiments at Langley Field.

The amounts of ice deposed on the propeller are varying in thickness, but it is certain that under some conditions they may envelop not only the blade tip, but even as far as to include the propeller boss or spinner where irregular deposits have been observed.

It has been thought that the centrifugal force would serve to offset any tendency toward deposit upon the propeller, but this is apparently erroneous and the explanation has been advanced that it is due to the instantaneous nature of the formation which is accounted for by the fact that water in the liquid stage may be encountered in the air at temperatures lower than the normal freezing point. This phenomena is permitted by the fact that the small droplets of water are under considerable pressure due to the surface tension of the liquid, the temperature then being below the freezing point. Immediately the surface tension is broken by striking the parts of the airplane, the transition to the solid state is instantaneous. Indeed, this may be the solution of the phenomena in so far as the irregular shape of the deposit upon the wings and other surfaces, the transition being so rapid as to prevent the water in its fluid state from following a streamline shape and producing the irregular "mushroom" shapes which have been observed.

In the flights which have been made by the National Advisory Committee for Aeronautics, conditions of a different nature with different consequences have also been encountered. These, in general, constitute a condition of clouds at temperatures 10° or more, below 32°F. In these conditions the formation of ice was again found, similar in some ways but in general, very different from the conditions at 32°F. This appears as a formation of softer ice or snow, along the leading edges of the exposed parts. The quantity is considerably less as there appears to be less adherence to the parts of the airplane, and the action of the wind appears to not only cut them down in quantity, but also to form a better streamline shape which has a lesser increase in drag, if any at all. As a matter of fact, it is possible to conceive an improvement of the aerodynamic shapes due to this deposition. The conditions are found and the consequences are the same whether upon struts or wires, or upon wings (Fig. 4).

A number of means of prevention or removal of this ice formation have been suggested and many have been tried, although the results of such trial are far from completion. These include methods of heating the affected parts, the oiling or greasing of the parts to reduce the tendency of the ice to adhere to the surfaces and the impregnation of this oil or grease with a chemical which would unite with the water to form a solution having a lower freezing point.

The oiling or greasing of the wings being the most simple expedient, has been most frequently tried and its efficacy does not appear from the history of its trial to be of any value. As a matter of fact, evidence is found of opinions that it hastened the formation of the ice. An explanation of this phenomena may be found in that, while a greased or oiled surface would normally shed water, under the condition of flight through rain or fog, the surfaces are bombarded with particles or drops of water at a velocity equivalent to the flight speed of the airplane which is sufficient momentarily to embed the drop of water in the oily surfaces where it is held for the small period of time necessary for it to freeze. Ice then may continue to form on this film of ice until eventually the oil is completely covered with a film which may be anchored either to the oil or by the force of the bombardment to the surfaces beneath the oil. The method cannot be considered seriously in view of reported evidence and experimental information in which ice has been observed in a thick coat over a large area of oil on the fuselage which was provided accidentally by leakage from the engine.

The addition of a chemical to the oil or grease may be of merit. It has the obvious disadvantage, however, of being "messy" and might possibly be to a great extent removed by the scrubbing action of the high velocity "rain" if maintained for any length of time.

The possibility of heating the surfaces appears possible by piping the exhaust through the leading edges of the wing. This method apparently has promise only in the case of a cantilever monoplane or of such other structure having a minimum of exposed structural parts. It would be necessarily impossible to apply such a method to an airplane similar to a DH-4 on account of the large amount of struts, wires, etc. Suggestion has been made that only a slight amount of heat applied to the leading edge of the wing might be sufficient to prevent ice formation and this is probably true, although it may be attended by only a change in the amount and character of the formation, that is, if the leading edge were heated and the balance of the wing was not, it might only prevent the formation along the leading edge and cause this formation to build up along the chord at other points and particularly at the trailing edge where the aerodynamic malformation might possibly be only slightly less disadvantageous.

In conclusion, it is evident that when these conditions must be encompassed, that if it is possible to rise to a higher, colder altitude they may be avoided almost equally as well as descending to a lower and warmer altitude. This alternative avoidance has the obvious disadvantage that it will not be effective after the formation of ice has progressed to any degree; perhaps even if it has begun at all, but it has the greater advantage in that higher and colder altitudes are always available whereas lower and warmer altitudes might not exist, as in the case where the ground temperature is below 32°.

The recommendation for the guidance of those who must encounter these conditions appears to lie entirely along the lines of their avoidance. For the information of the pilot, a temperature thermometer of a distance type should be installed in all airplanes indicating from a remote "bulb" on a strut or wing of the airplane the temperature of the surrounding atmosphere. He may then be guided to avoid the combination of conditions which produce the greater hazard as has been outlined in this note.

Langley Field, Va.,

May 22, 1928.

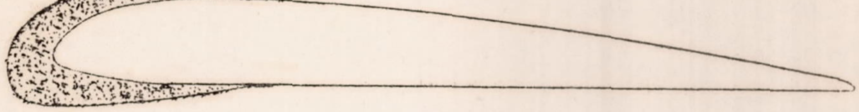

Fig.1

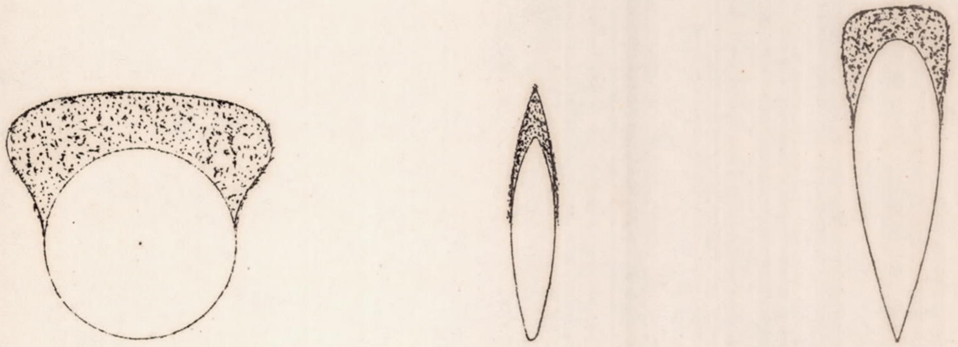

Fig.3

Fig.4

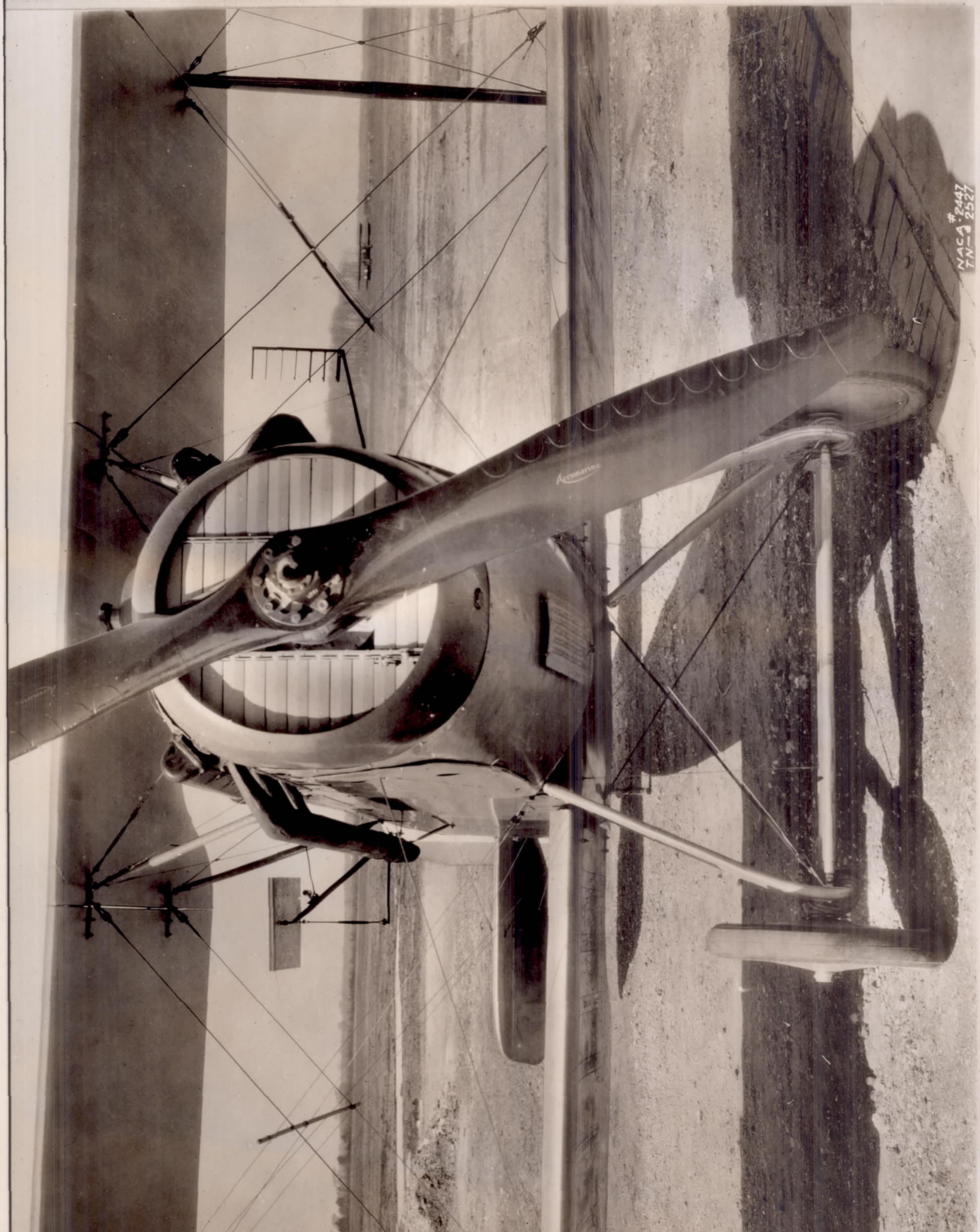

Fig. 2 VE-7 airplane and models used in ice formation study