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SUMMARY

The various possible means of preventing ice adhesion on airplane surfaces are critically reviewed. Results are presented of tests of the adhesive forces between ice and various solid and liquid surfaces.

It is concluded that the de-icing of airplane wings by heat from the engine exhaust shows sufficient promise to warrant full-scale tests. For propellers, at least, and possibly for certain small areas such as windshields, radio masts, etc., the use of de-icing or adhesion-preventing liquids will provide the best means of protection.

INTRODUCTION

The de-icing of airplanes in flight presents a serious problem to the air-line operator. Although various means of de-icing airplane surfaces have been suggested and tried, no entirely satisfactory method has been perfected. The accretion of ice on the aircraft surfaces may be prevented by:

1. Removing the ice mechanically.

2. Preventing freezing of the water on the surfaces by maintaining the surfaces at a temperature above the freezing temperature of water.

3. Providing a surface on the wing to which ice will not adhere.

The first method is now employed in service by the use of the Goodrich de-icer on the leading edge of the wing. (See references 1 and 2.) The second method has been suggested (references 3 and 4) but thus far no full-scale experiments on its use have been reported. The third method has been successfully used on airplane propellers and has been tried on other surfaces.

In the development of both the first and the third methods, the adhesion of ice to various surfaces becomes of interest. It is the purpose of this paper to present data relative to the adhesion of ice to various solid and liquid surfaces. Although the data do not lead to any successful solution of the de-icing problem, they are presented with the idea that a better understanding of the problem will result. The tests were conducted at the Committee's laboratories at Langley Field.

METHODS AND APPARATUS

Tests were conducted to measure quantitatively or qualitatively the force required to remove ice from various sufraces. The surfaces were maintained at temperatures below 32° F. by placing them in a box containing sufficient solid carbon dioxide ("dry ice") to hold the inside of the box at the desired temperature. A window was provided in the side of the box for visual observation. All temperatures were measured either with a mercury thermometer or with a thermocouple and a potentiometer. The box was sufficiently insulated so that there was no difficulty in maintaining a constant test temperature.

The adhesion of ice to solid surfaces was measured both quantitatively and qualitatively. In the quantitative measurements, blocks 1 inch square were made of the material to which the adhesion of the ice was to be measured. These blocks were held together by an adhesive tape in such a manner that the blocks were separated by about one-eighth inch. This space was filled with water and the blocks were placed in a second cold box until the water was frozen. The specimens were then read for testing. (See fig. 1.) After the water was frozen, the hook on one block was fastened to the bottom of the first cold box. A beam balance was mounted on the top of the box and a rod extended from it through a hole in the top of the box to the hook on the other block. The beam was then loaded until the blocks were pulled apart.

The shear force required to separate the blocks was measured by means of a hydraulic ram. This ram consisted of a lapped plunger of known cross-sectional area actuated by a known hydraulic pressure.

Care had to be exercised to obtain reproducible results. The greatest variation occurred when the blocks with the ice between them were cooled to too low a temperature during the freezing process. If the temperature of the ice was brought to too low a value (considerably below 0° F.), the ice tended to crumble. The blocks were always left in the test box until a thermocouple indicated that they were at the desired temperature. In several cases, the blocks were coated with other than metallic materials.

Most of the de-icing or adhesion-preventing liquids were tested qualitatively because of the difficulty of devising a satisfactory procedure for measuring adhesion either in tension or in shear with a liquid surface. In these tests, a metal block in the cold box was coated with a thin layer of the liquid. One to four drops of water from an ice bath were dropped on the liquid surface. After the water had frozen, it was pushed off the block by hand and the relative force was estimated.

RESULTS

In table I are tabulated the results obtained in the determination of the tensile force required to remove the ice from different materials. These results can be divided into three classifications: (1) With ice adhering to a solid surface, the failure occurred in the ice (fig. 2) at a loading of about 140 pounds per square inch; (2) with ice adhering to a greasy surface, the failure occurred between the ice and the grease at a loading equal to or a little greater than atmospheric pressure; and (3) with the ice adhering to a wet surface, the failure occurred between the ice and the wet surface and the tensile force required to cause the separation was too low to permit the blocks to be installed on the balance.

Other tests made with these same blocks at a later date gave forces that may have varied from the preceding values for the solid surfaces by as much as 100 percent. In every case, however, the failure was in the ice itself, which did not break loose from the solid surface. It seems that, unless the experimental technique is very closely reproduced, results from day to day may vary; but, in every case, the force required to break the ice was exceedingly high and, in every case, the ice adhered to the specimens after failure. These forces as measured are much too high to permit mechanical removal directly from the metal surface to be considered as a means of de-icing aircraft surfaces.

Tests were made in which a piece of airplane fabric covered with aluminum dope was placed in the ice midway between the two blocks. The same procedure was followed with a 0.005-inch piece of polished duralumin sheet. The tensile force required to break the blocks apart was approximately 30 pounds per square inch. In these cases, the ice broke cleanly from the doped fabric and from the duralumin sheet. In order to determine whether the polished surface of the duralumin sheet caused the ice to break from the sheet, a block of duralumin was given a mirror finish. The ice adhered to this block as it did to the other duralumin blocks. (See table I.) It is believed that the failure of the ice to adhere to the sheet or to the fabric was caused by the fact that the thin sheets mounted in the center of the ice between the two metal blocks resulted in nonuniform loading.

As a further test of the effect of surface smoothness, water from an ice bath was dropped on glass surfaces that had been ground and polished for use in photographic work. These surfaces are probably the smoothest available at this laboratory. The small drops of ice (about one-fourth inch in diameter) adhered to the glass surface with sufficient force so that they could not be pushed off the glass without first causing failure of the ice.

The fact that the ice was removed from the thin sheet of metal or the fabric with a comparatively low force probably accounts for the successful operation of the Goodrich de-icer, the ice breaking loose from the rubber boot during its inflation and deflation. Qualitative tests with rubber did not indicate that the ice was removed from a rubber surface with any greater ease than from a hard surface. With the boot, however, the load can be concentrated in a small area so that it is possible to cause the rubber to break loose from the ice. Although the boot causes the ice cap to break from the boot, flight tests have shown that pieces of ice adhere to the boot during successive inflations and deflations and that, although they present a comparatively large area to the air stream, they are not blown loose from the rubber.

In the shear tests, three classifications were found: (1) With the ice adhering to a solid surface, the shear force required to remove the ice was 65 to 85 pounds per square inch; (2)with the ice adhering to a greasy surface (such as compound A in table II or vaseline), the shear force was 2 to 9 pounds per square inch and had to be continuously applied to remove the ice completely; and (3) with the ice adhering to a wet surface (mercury amalgam), the shear force was 3 to 12 pounds per square inch. In cases (1) and (3), once the plunger causing the ice to shear had started to move, the ice was pushed completely from the specimen by the expansion of the oil in the hydraulically operated plunger. The low values of shear force for cases (2) and (3) are not any too accurate. They are probably on the high side. Tests made with solutions placed on the metal block, such as calcium chloride in alcohol, also showed a small shear force.

These results have not shown any indication that a solid surface can be obtained to which ice will not adhere. The results indicate that ice will not adhere to a liquid surface and it seems to be immaterial of what substance the liquid surface is formed. Additional tests have been made with the metal blocks covered with liquid surfaces. A pour-point depressor or lubricating oils and other water-insoluble liquids have been tried. In these tests, water from an ice bath was dropped on the liquid surface covering the block, which was maintained at a temperature between 32° F. and 0° F. In each case, the ice formed by the freezing water was easily removed. When the water was dropped directly on the solid surface, the ice adhered strongly to the surface and the degree of adherence increased through the first several minutes that the ice was allowed to remain.

The use of a water-soluble fluid to lower the freezing point has resulted in a satisfactory solution to the propeller-de-icing problem, at least for the present. Some improvements may be necessary with the larger propellers now in prospect because of the increased difficulty of distributing the liquid over the propeller surface and the lower centrifugal force available for removing ice.

The solution now being used on propellers consists of about 15 percent glycerin in ethyl alcohol (probably about 190 proof). The substitution of methyl alcohol for the ethyl alcohol should result in a 25-percent saving in weight of solution if the question is one of lowering the freezing point of water to a certain degree. This lesser weight results from the fact that, for ideal solutions, the addition of a gram molecule of any nonionizable material to a given amount of a particular solvent lowers the freezing point a definite amount. For substances that do not give ideal solutions, the lowering is not so great. It so happens that alcohol-water solutions are reasonably ideal and, consequently, there is no point in considering any compound having a molecular weight in excess of that of ethyl alcohol. Comparatively few organic compounds in this range are suitable because they must be quite soluble in water at low temperatures, they must not be too volatile, and they must be noncorrosive.

If the alcohol could be fortified with some substance capable of ionizing in water solution, there is some possibility of considerably improving the ability of alcohol to lower the freezing point of water. The molecular weight of the salt must again be as small as possible. Most salts do not have sufficient low-temperature solubility in both alcohol and water. Furthermore, most salts are corrosive. There remains, however, the possibility of improving, on a weight basis, the ability of pure ethyl or methyl alcohol to lower the freezing point by a factor of perhaps two or three by the addition of alcohol-soluble and water-soluble salts of low molecular weight.

Whether it is necessary to lower the freezing point of all the water striking the airfoil to the temperature of the ambient air is not known. Although lowering the freezing temperature of only part of this water will probably prevent ice adherence by causing a liquid film to be maintained on the metal surface, ice can build up on this film and necessitate removal by mechanical means. To lower the freezing point of all the impinging water to 0° F. would require a weight of solution of at least 20 percent of the weight of water striking the surface. In the case of the ethyl alcohol-glycerin solution, a considerably greater amount would be necessary.

Everything considered, the use of a freezing-point depressor for airplane wings does not look encouraging unless adequate mechanical means can be supplied to remove the ice from the liquid interface separating the ice from the wing. The possibility of finding a substance better than methyl alcohol is not very great and its use over extensive surfaces for preventing ice adhesion on airplane wings would involve a prohibitive weight of de-icing solution if much water has to be treated. Such a solution, however, is of considerable interest in preventing ice adhesion on small areas such as windshields, propellers, radio masts, and possibility control surfaces, where the amount of liquid used is not of primary importance.

Any water-insoluble liquid that will adhere to the airplane surfaces will undoubtedly prevent ice adhesion except for the atmospheric pressure holding the ice to the liquid interface and the possibility that the water may penetrate the protective film and adhere to the surface. A flight test was made with a section of an airplane wing covered with copper which, in turn, was coated with an amalgam of mercury. A water spray was directed against the leading edge of this section of the wing while the airplane was flying in air below the freezing temperature. Under these conditions ice formed on the mercury-covered surface. At the end of the flight all the mercury had been washed or flown from the leading edge. Visual observation during an icing test in flight has shown that ice formed on the lower surface of the wing does not immediately drop off when the wing surface is raised above the freezing point. Instead, the ice moved slowly toward the rear of the wing adhering to the liquid interface formed by the melting ice. Consequently, it is concluded that the use of a water-insoluble liquid for preventing adhesion can be used only in conjunction with some mechanical force for removing the ice. This same conclusion applies to the water-soluble liquid except in those cases where the amount of liquid supplied is sufficient to lower the freezing point of all the water striking the surface. The use of an insoluble liquid to prevent ice adhesion should require a smaller amount of the liquid than the use of a soluble liquid, provided that the surfaces are at all times covered with the liquid.

A method of applying these liquids, which has not been discussed, consists of having the liquid mixed with a greasy or gelatinous binder. Compound A, which is apparently used to a certain extent in England, and compound B are made in this manner. The paste or thermally softened material is spread over the airplane surface and acts as a binder for water-soluble materials. The use of these preparations is based on the idea that the water-soluble constituents will maintain a liquid interface between the ice formed and the airplane surface. Although such materials will prevent the ice from adhering directly to the airplane surface, it does not seem reasonable to believe that such compounds will, of themselves, prevent the ice from remaining on the surface because of the atmospheric pressure, which must be overcome before the ice will be dislodged.

A preparation somewhat similar to compound B that might have even better possibilities is a mixture of gelatin and some water-soluble material. Such a substance similar both in appearance and action to compound B was made by mixing ethylene-glycol and gelatin. This mixture, when melted at a temperature of about 160° F. and painted onto the metal surface hardened to a rubbery consistency. This characteristic, common to both this mixture and compound B, may be important in that it tends to prevent water drops which impinge on the coating from penetrating through the coating and adhering to the metal surface. A metal surface coated with this mixture was placed in the cold box, which was maintained at a temperature of 12° F. Water from an ice bath was dropped on the surface. The drop froze but not so quickly as a drop placed directly on the metal. A liquid film was maintained between the ice and the mixture of ethylene-glycol and gelatin. The ice could be moved around freely on the surface but, when the ice was moved slightly, the surface-tension forces tended to bring the ice back to its original position. This action occurred at temperatures down to 0° F. If the ice was allowed to remain for some time (say 15 minutes), it melted.

Both compound A and compound B have been tested in flight; ice forming on the surface covered with either of the preparations adhered to the surface. In the flight tests, no mechanical means was available to measure the force required to remove the ice but, from the laboratory tests, it seems safe to assume that the force would not have been greater than the air forces tending to hold the ice to the surface.

CONCLUSIONS

The most important conclusions drawn from the present tests are possibly not new, but they seem to be quite definite.

1. Ice will adhere to any solid surface tried thus far with a force greater than the cohesive forces within the ice.

2. Ice will not adhere to a surface provided that

there is a liquid interface between the ice and the surface. If such a liquid interface is formed, the force required to remove the ice will be little more than the aerodynamic or aerostatic forces tending to hold the ice to the surface.

3. The outlook for preventing ice formation on the surfaces of an airplane wing by means of some liquid surface is not encouraging. The amount of liquid required will probably be large and some mechanical force is necessary to overcome the air forces in order to remove the ice. The use of such liquids for windshield de-icing or for small surfaces may be successful.

4. For propellers, where a centrifugal force is always available, the use of liquids for de-icing will probably continue to be the most efficient method.

5. Although wind-tunnel tests have indicated that heating the wings of an airplane as a means of preventing ice formation is feasible, no full-scale tests have been made to determine the practicability of the method. It is believed that such tests should be conducted as soon as possible.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 7, 1939.

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TABLE I

Tensile Strength Data

Material	Tensile strength (lb./sq. in.)	Type of failure	Temperature (°F.)
Brass	130	1	21
Copper	152	1	23
Duralumin	132	1	25
Stainless steel	139	1	21
Micarta	53	2	18
Pour-point depressor (viscous liquid)	15	1	21
Compound A	12	3	18
Vaseline	33 15 0	1 3 3	25 25 14
Mercury amalgam on brass (surface wet)		Failed while being placed on balance	
Mercury amalgam on brass (surface wiped off)	7 - 13	3	7

[1]Ice broke on plane normal to tensile force midway between faces of specimen.

[2]Ice broke irregularly but remained adhering to specimen surface.

[3]Ice did not break; failure between ice and surface of specimen.

TABLE II

Composition of Commercial De-icing Pastes

	Percent
Compound A:	
Lubricating grease (mineral oil type)	20
Sodium chloride	25
Anhydrous dextrose	45
Water	10
Compound B:	
Glue	12
Glycerin	25
Water	63

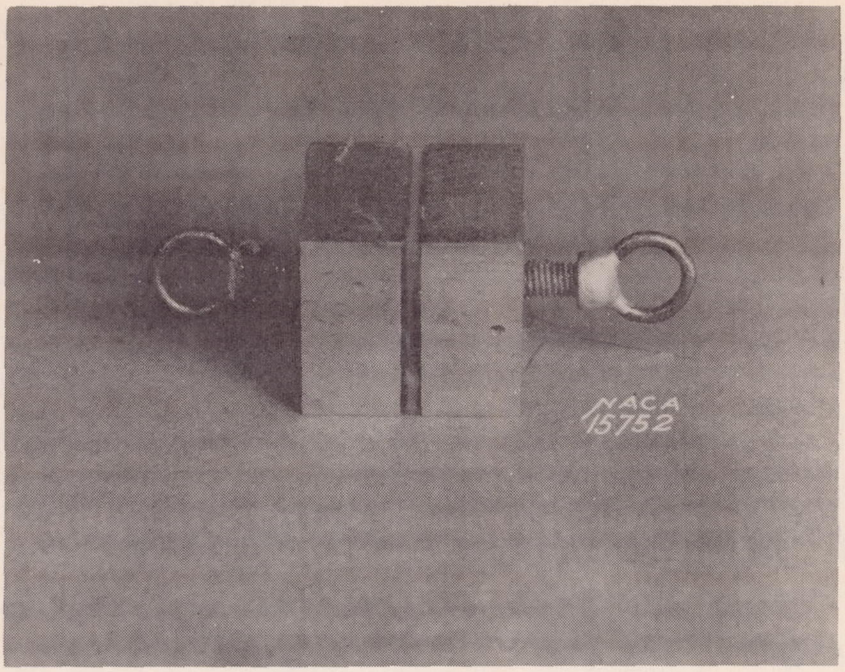

Figure 1.- Metal blocks held together by ice for tensile-strength tests.

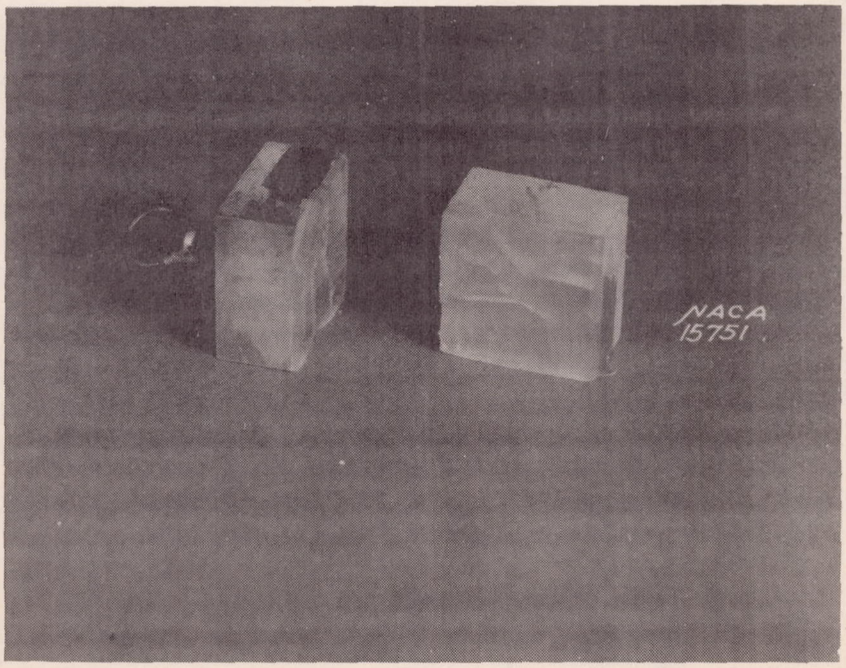

Figure 2.- Failure of specimen in tension. Failure occurred in ice and not at ice-metal interface.