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INVESTIGATION OF AN ELECTRICALLY HEATED AIRPLANE WINDSHIELD FOR ICE PREVENTION

By Lewis A. Rodert
Langley Memorial Aeronautical Laboratory

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SUMMARY

A study was made at the National Advisory Committee for Aeronautics laboratory of the operation of an electrically heated glass panel, which simulated a segment of an airplane windshield, to determine if ice formations, which usually result in the loss of visibility, could be prevented. Tests were made in the 7- by 3-foot ice tunnel, and in flight, under artificially created ice-forming conditions.

Ice was prevented from forming on the windshield model in the tunnel by 1.25 watts of power per square inch with the air temperature at 23° F. and a velocity of 80 miles per hour. Using an improved model in flight, ice was prevented by 1.43 watts of power per square inch of protected area and 2 watts per inch concentrated in the rim, with the air temperature at 26° F. and a velocity of 120 miles per hour. The removal of a preformed ice cap was effected to a limited extent in the tunnel by the use of 1.89 watts of power per square inch when the temperature and velocity were 25° F. and 80 miles per hour, respectively.

The results indicate that service tests with an improved design are justified.

INTRODUCTION

Although various devices have been proposed for preventing the formation of ice on airplane windshields, none of them have been developed to give satisfactory performance. The problem of preventing ice on windshields has, therefore, been included in the general investigation of the icing problem now being carried out by the National Advisory Committee for Aeronautics. It is intended to investigate various thermal, mechanical, and chemical means in order to determine some satisfactory method of solving the problem.

One method that appeared promising was the use of an electrically heated windshield in which the heating elements were immersed in a transparent liquid between glass plates. Preliminary tests of an arrangement of this type were made in the N.A.C.A. ice tunnel and indicated that further tests would be justified. An improved model was constructed therefore and was tested in flight. This report presents the results of the investigation of this method for windshield ice prevention in the tunnel and in flight.

APPARATUS

Ice-Tunnel Model

The first model of the electrically heated windshield was tested in the 3- by 7-foot N.A.C.A. ice tunnel, in which a temperature of 20° F. and a velocity of 80 miles per hour could be maintained for continuous operation.

The section of windshield model tested was 10 inches square, set into an inclined plane. Figure 1 shows a photograph of the model mounted in the tunnel and a section view illustrating the housing. The test panel was made up of two panes of glass 1/8 inch thick, separated by a 1/4-inch gap. The space between the two glass panes contained both the electric heating wires and also ethylene glycol to improve the transmission of heat from the wires to the glass. The requirements were that the liquid filler be a nonconductor of electricity, be a good heat conductor, have about the same index of refraction as glass, and remain transparent over the temperature range from 0° to 120° F. A bakelite spacer running around the test panel and cemented to the glass panes provided the seal necessary to retain the liquid. A tube was connected to the entrapped region and was used both as a filler duct and as a header into which the liquid could flow when expanded by a temperature rise.

Measurement of the power consumed by the unit was made from observations of the instruments noted on the wiring diagram in figure 1.

A spray nozzle located in the tunnel air stream supplied waterdrops simulating an atmospheric precipitation for the production of icing conditions.

Flight Test Model

Following the ice-tunnel tests, a model for flight testing was made and installed on the windshield of a Stinson four-place cabin monoplane. The test panel, allowing vision through a rectangular area, 5 by 10 inches, was set into the regular windshield. The outside dimensions of the test frame were 8.1 by 13.1 inches. The construction of the flight test model was similar to that of the tunnel model, with the exception that a heating element wire was enclosed in the rim to provide for additional heating at the panel edges. A section drawing of the construction at the edge and a diagram of the electrical circuit are shown in figure 2. The assembled model prior to installation is illustrated in figure 3.

The power input was computed from the ammeter readings and the resistance of the heating circuits, according to the equation, Power = $(\text{Current})^2 \times$ Resistance.

There were eight wires heating the pane, spaced evenly over the 5-inch width 0.56 inch apart. The liquid dielectric space was 1/4 inch and was filled with ethylene glycol as in the tunnel model.

Icing conditions were simulated by a spray nozzle located ahead of the windshield and as near to the rear face of the propeller as safety permitted. The spray nozzle which was movable in flight from the cabin permitted complete coverage of the windshield with waterdrops. Heated air from the radial air-cooled engine was deflected from the region of the test panel by a baffle over the engine cowling. This arrangement was considered necessary in order to obtain similar air-temperature conditions to that of a windshield not located back of an engine. Preliminary flight tests indicated that this was effective since temperature measurements made in the air near the test panel gave values within 1° F. of that read from a strut thermometer located outside the propeller slipstream. Power for the heater circuits was provided by two 12-volt, 34-ampere-hour aircraft batteries, connected in parallel. Desired air temperatures for the tests were obtained by flying at suitable altitudes.

TESTS AND RESULTS

The rate at which heat is given up by the surface of an airplane windshield to the air stream is affected, among other things, by the temperature of the air and waterdrops entrained with it, and the actual waterdrop content of the air. Although no measurement of the water temperature was made, it was thought that some supercooling existed during most of the tests. The air temperatures during the tunnel tests were perhaps a little lower than might be found in nature considering the amount of water present. It is believed that the range of values for water volume and temperature and air temperature used represent a combination of conditions that is typical of a fairly severe ice storm, although apparently not as severe as has been reported in some isolated cases.

Inasmuch as the problem of ice prevention differs from that of ice removal, both types of test were made. The prevention tests were made by closing the electric heater circuit a short time before the water spray was turned on. The minimum power condition was sought at which ice formations could be prevented over the test panel. In the case of the flight model, this involved various combinations of power for the pane and rim heaters. Removal tests were made allowing ice to completely cover the test panel prior to closing the heater circuits. Although it was never possible to determine exactly how thick the ice had formed before heat was applied, it is believed that in most removal tests about 1/8 inch was on the glass.

The results of the tunnel tests are assembled in table I, and those of the flight tests in table II. Figure 4 shows the tunnel model after it has prevented ice from forming. Figure 5 shows the tunnel model after an unsuccessful attempt to remove a preformed ice cap. Figures 6 and 7, which are photographs taken after flight tests, indicate the results of operation of the flight test panel.

DISCUSSION

The two problems, ice prevention and ice removal, will be discussed independently. In order to avoid confusion, prevention should be considered as the action of preventing any ice crystals from forming on the panel.

Removal, on the other hand, will be referred to as the action of removing ice formations after an appreciable amount has adhered to the surface.

The investigation shows that the formation of ice was prevented on the airplane windshield in flight by about 1.43 watts of electric energy supplied to a heating element for each square inch of surface to be cleared at 120 miles per hour. The power required to prevent ice at higher air speeds than 120 miles per hour can be roughly approximated from the equation (reference 1).

$$P_V = 1.43\ (V/120)^{0.78}$$

in which P_V is the power in watts per square inch required at the higher velocity V. At 200 miles per hour, the required power would be 2.12 watts per square inch.

The above stated requirements, however, ignore the difficulty that was experienced with ice from the unprotected area tending to overhang the heated area. Because of this difficulty, it was concluded after the tunnel tests that heat concentration was necessary at the edges of the protected area. It was thought that such an arrangement would not only prevent the ice from overhanging the protected area, but would also cut through any preformed ice film and thereby assist the quick removal of such ice. The flight model, therefore, was provided with a heating element in the rim surrounding the heated panel.

Flight tests indicated that the rim heater prevented all overhanging ice film from the unprotected areas. It was observed, however, that the tendency to overhang was confined to the edge across which the air stream first passed - that is, the lower edge - and could be prevented there by about 2 watts per inch of rim length. As the power was reduced during the ice-prevention tests, ice formed first between the bottom heating wire and the lower edge of the transparent area. It was concluded from this observation, that the first wire should have been located quite near the leading-edge rim which should also be heated as noted above, and that the spacing of the other wires should have been less at the bottom and become progressively greater toward the top. This should provide a more effective release of energy and therefore permit a reduction of the heating power.

The removal of an ice coating over the windshield by the electric heaters tested was affected by factors not related to the problem of ice prevention. Although the power required to melt the ice free from the glass was smaller than that required for ice prevention, the problem of getting the unbonded ice cap off the transparent area offered other difficulties. As previously noted, heat was concentrated at the edges to prevent bonding to the ice over the unprotected areas. In flight it was indicated that about 2 watts per inch of rim would free the ice at the edges within 10 minutes after heat was applied.

The amount of power required to effect the removal of a preformed ice cap by melting in a relatively short time is thought to be excessive. According to the tunnel results, at 80 miles per hour, about 1.9 watts of power per square inch of area would be required to remove an ice cap in 15 minutes. Observations of the tunnel tests indicated that by causing the heated face of the test panel to protrude from the remainder of the windshield and by concentrating additional heat to the panel edge, the ice would be permitted to slide sideways and clear the test panel after its bonds had been melted. It was thought that by this means the ice cap could be removed quickly without excessive power. The flight tests of this feature were inconclusive. However, it was indicated that the principle was correct but that some additional means, possibly mechanical, were needed to insure immediate removal of the ice cap.

The results seem to indicate that the type of electrically heated windshield tested may have some practical application and that future development through service testing is justified. Any future construction should consider the following recommended design criteria which are based on the test results and impressions gained from qualitative observations during the investigation:

1. If the operator turns the heater on when icing conditions are impending or immediately after icing has started, in the same way that the air-speed mast heaters are used, the power supply for the pane heater may be determined from the equation

$$P_W = 0.035\ V^{0.78} \text{ watts per square inch}$$

in which V is the velocity in miles per hour.

2. Additional protection, particularly against overhanging ice, may be had by heating the leading-edge rim with about 2 watts of power per inch of rim, and by causing the protected surface to protrude about 1/2 inch from surrounding unprotected surfaces.

3. When a considerable ice cap has been allowed to form, the entire rim should be heated with about 2 watts of power per inch of rim in addition to the pane heater.

4. The outer protruding face of the heated windshield should have a smooth surface at the rims in order that a preformed ice cap which has been melted free from the protected surface may be removed either by the air stream or by some auxiliary mechanical means.

5. The face area of the heated windshield rim should be as small as possible.

6. The most effective use of pane heating power may be obtained by a relatively close spacing of the wires at the leading edge with a progressively increased spacing toward the rear.

7. The air stream should cross the face of the panel perpendicularly to the direction of the pane heating wires.

CONCLUSIONS

1. The prevention of ice on the windshield model was accomplished in the tunnel with 1.25 watts of electric power per square inch when the temperature and velocity of the air stream were 23° F. and 80 miles per hour, respectively.

2. Ice was prevented on a second and improved model in flight using 1.43 watts of electric power per square inch of transparent surface augmented by a rim heater using 2 watts per inch of rim with the temperature and velocity at 26° F. and 120 miles per hour, respectively.

3. The removal of a preformed ice cap was partially successful in the tunnel with 1.89 watts of electric power

per square inch when the temperature and velocity were 25° F. and 80 miles per hour, respectively. Design improvements and possibly mechanical assistance are needed for the rapid removal of a preformed ice cap.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 21, 1939.

REFERENCE

1. McAdams, William H.: Heat Transmission. McGraw-Hill Book Co., p. 237.

TABLE I

WINDSHIELD ICE REMOVAL AND PREVENTION TEST RESULTS

Tunnel Tests

Heated area, 10 by 10 inches. Transparent area, 9 by 9 inches.

Type of test	V, m.p.h.	Air temperature °F.	Power required watts/sq.in.	Comments
Prevention	80	23	1.25	Ice prevented (see fig. 4), formations at edge of test panel 1-1/4 inches thick. Vision clear. Ice showed some tendency to build out and over panel at the entering edge.
Removal	80	23	1.60	Ice removed from about 20 percent of panel in 15 minutes (See fig. 5.) Ice melted beneath formation but weblike crust not removed except at top of panel.
Removal	80	25	1.89	Ice removed from 30 percent after 10 minutes. Loss of ethylene glycol due to leakage, 60 percent. Ice not removed over that section not containing ethylene glycol. Tests discontinued due to failure of model.

TABLE II

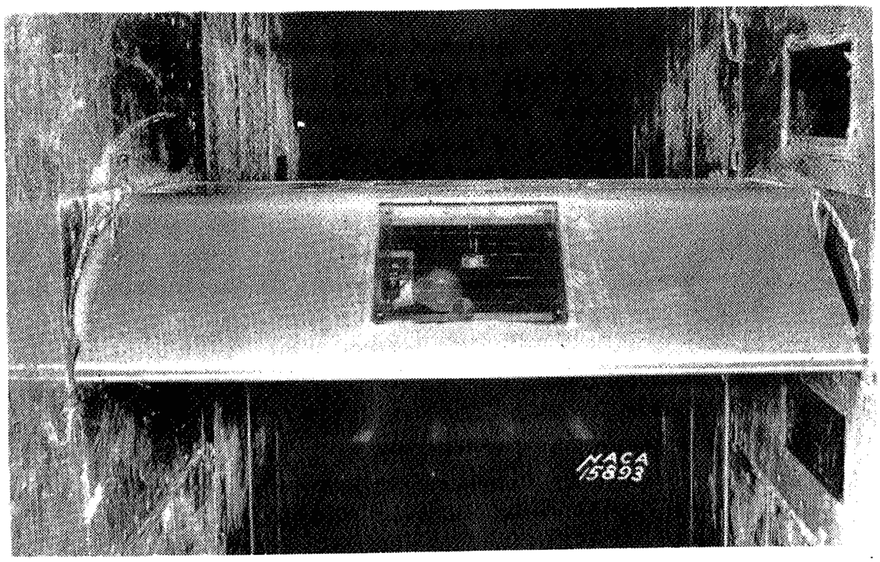
WINDSHIELD ICE REMOVAL AND PREVENTION TEST RESULTS

Flight Tests

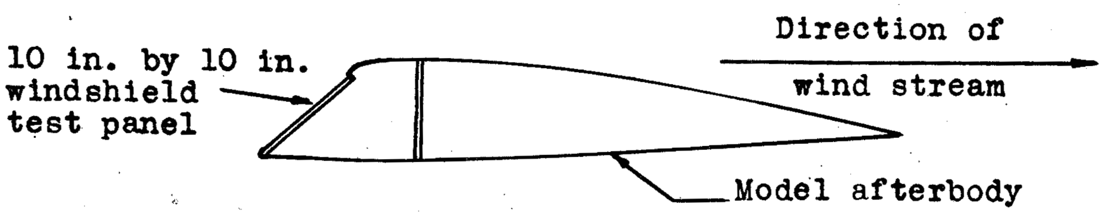
Heated area of pane (transparent) = 5 by 9.75 inches. Total heated area, 8.1 by 13.1 inches. Cabin temperature, 40° F.

Type of test	V, m.p.h.	Air temperature °F	Power required		Altitude ft.	Comments
			Pane, watts per sq.in.	Rim watts		
Prevention	95	26	1.43	63	12,000	Ice prevented over 106 sq.in. in continuous operation, also small preformed formations were removed. Visibility clear. (See note.)
Removal	90	25	1.43	63	12,700	After 11 minutes ice melted free from pane and was blown away from 80 percent of the test panel. The lower edge remained covered due to insufficient power in lower rim heater. Slight blurring between wires of test panel. Visibility poor.
Removal	98	25	.55	250	14,800	After 8 minutes ice formation over panel melted free and moved sideways until contact was made with ice over adjacent area. Rim power greater than needed.
Prevention	120	26	1.43	63	12,000	Ice prevented from forming over transparent region. (See note.)

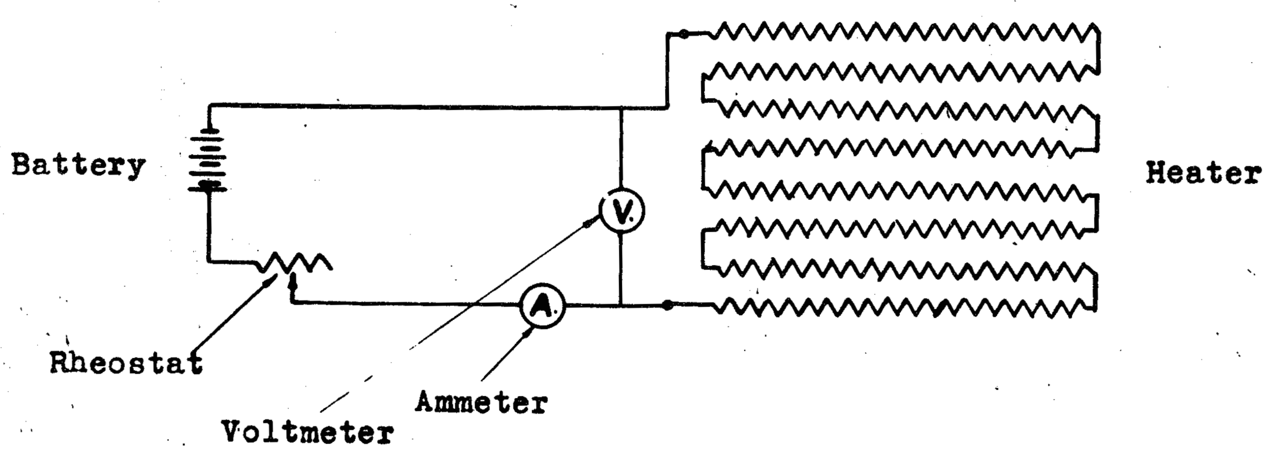
Note: The ice-forming conditions did not require a rim heater except at the leading edge. Ice was removed from the unprotected areas along the sides and at the top of the heated panel, indicating that the rim heaters along those edges were not required.



View of model mounted in tunnel



Section view



Electrical heating circuit

Figure 1.- Tunnel model

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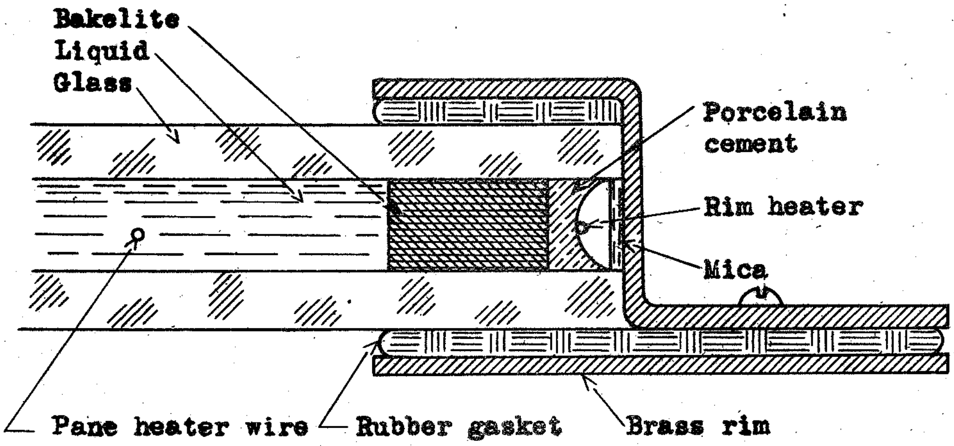

Section of
electrically heated windshield
ice eliminator.

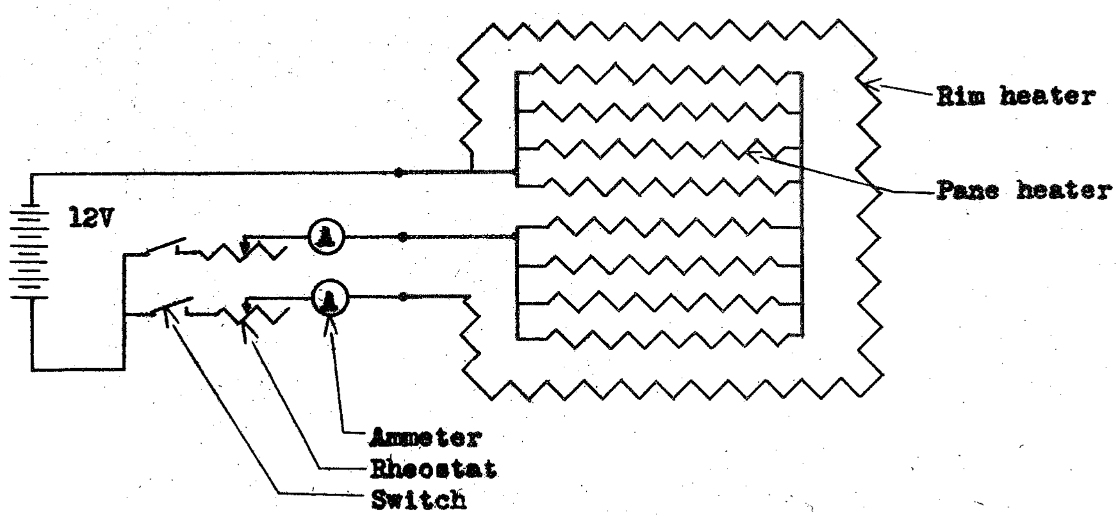

Figure 2.- Wiring diagram of electrically heated windshield ice eliminator.

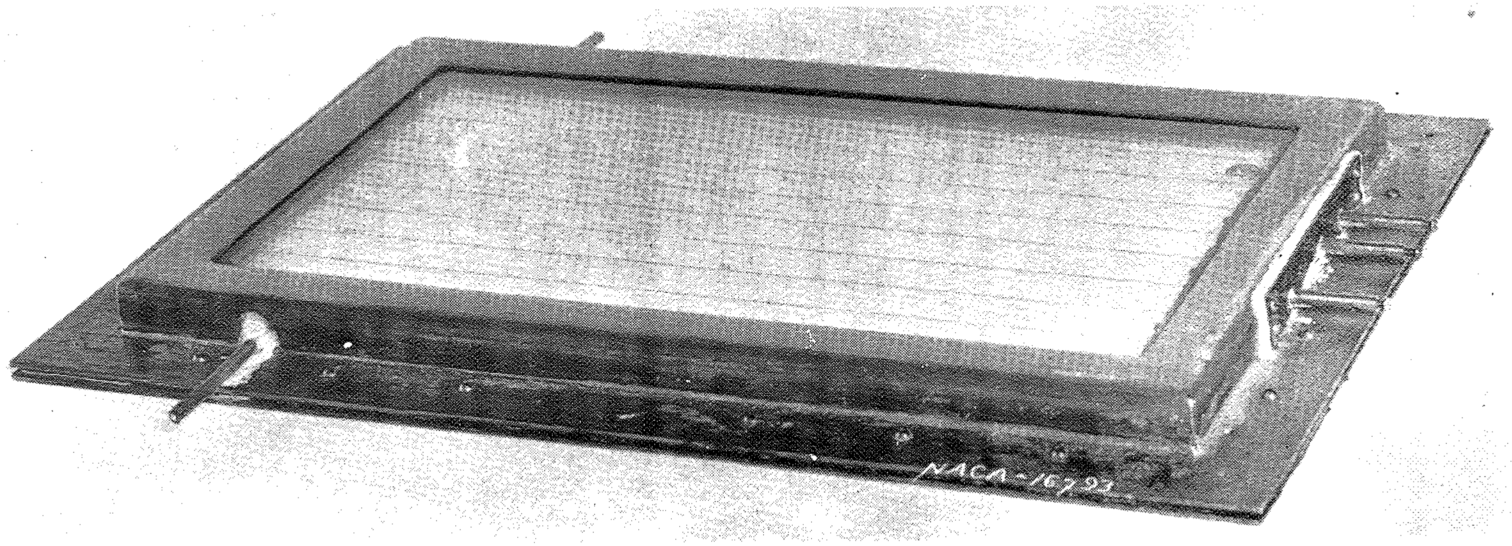

Figure 3.- The flight-test model before installation in the airplane windshield.

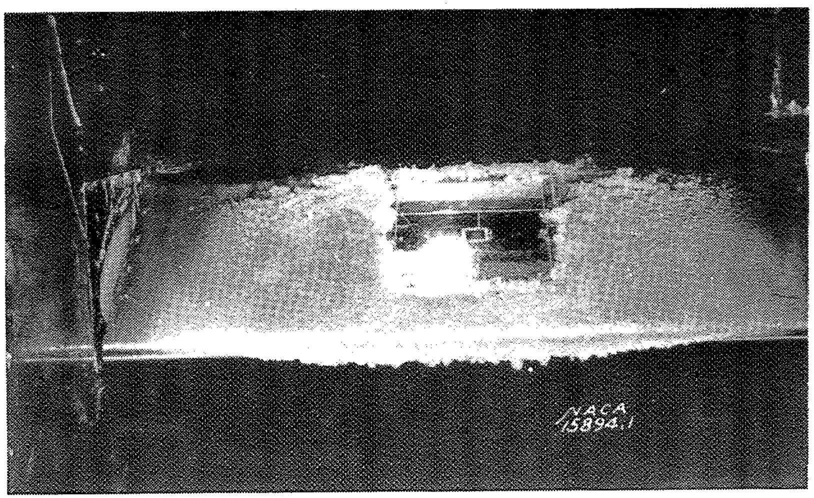

Figure 4.- The tunnel model after an ice-prevention test.

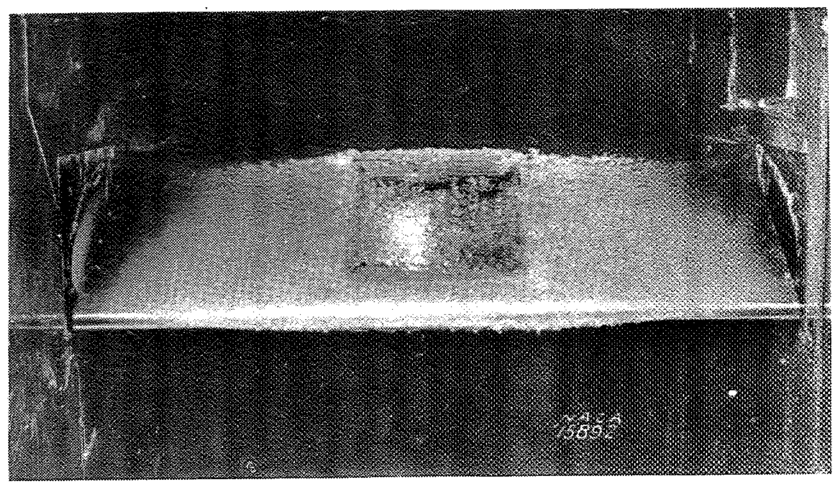

Figure 5.- The tunnel model after an ice-removal test.

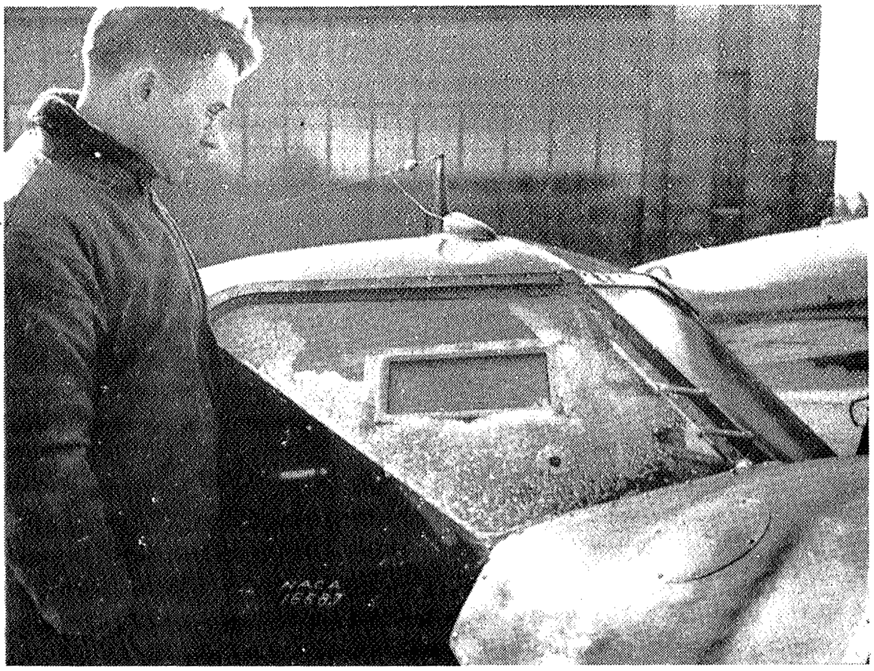

Figure 6.- Ice removal and prevention results illustrated photographically. A large part of the ice on the unprotected region blew away by the air stream during descent.

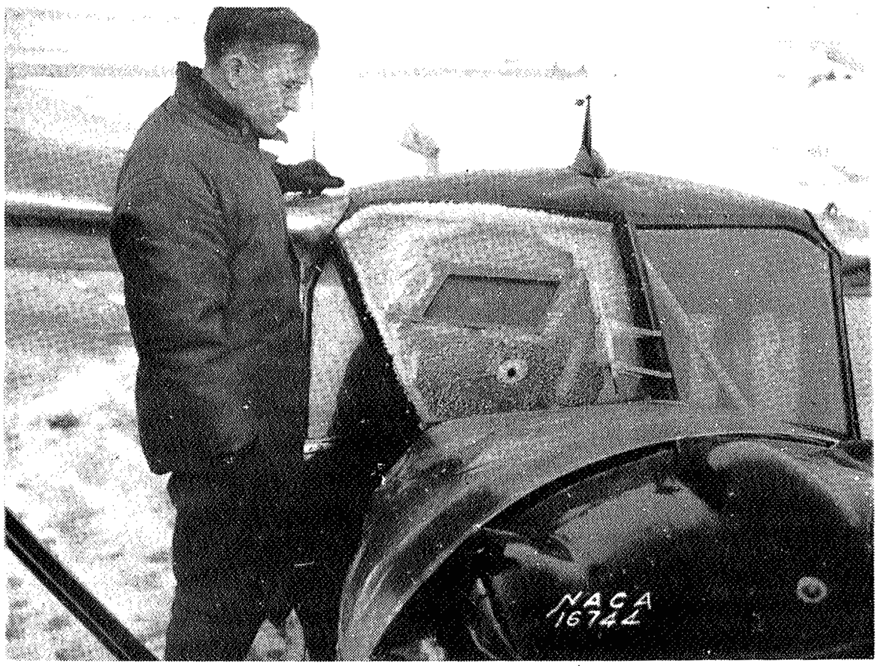

Figure 7.- Ice removal and prevention results illustrated photographically.