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TESTS OF THERMAL-ELECTRIC DE-ICING EQUIPMENT FOR PROPELLERS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

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SUMMARY

Flights were made in natural icing conditions at the NACA Ice Research Project, Minneapolis, Minn. to test several designs of thermal-electric propeller de-icing blade shoes and a hub-generator design. It was found that a minimum average unit power of 2.5 watts per square inch of blade-shoe area would protect the propeller blades at the test conditions. The most satisfactory blade shoe of the three designs tested extended to the 20-percent-chord point and to 90 percent of the blade radius. A concentration of heat in the leading-edge region of this shoe was found to reduce the power input necessary for satisfactory de-icing. A satisfactory thermal design of blade shoe and a hub generator of sufficient capacity were developed.

INTRODUCTION

The present research was undertaken as part of the ice-protection research program of the NACA being conducted at the Ames Aeronautical Laboratory, Moffett Field, Calif. The development of an electrically heated blade-shoe and hub-generator combination for propeller de-icing has been carried on by the National Research Council of Canada, the Hamilton Standard Propellers Division of the United Aircraft Corporation, the U.S. Army Air Forces, and the NACA, with the cooperation of the B. F. Goodrich Company. The work reported herein is a continuation of that of the National Research Council on this problem. The blade shoes manufactured by the B. F. Goodrich Company were designed on the basis of results of previous tests conducted by the National Research Council and original development work by the Goodrich company.

The purpose of the present tests was to develop a satisfactory blade-shoe and hub-generator combination and to provide additional data on which future designs could be based. Observations were made of the effectiveness of three different blade shoes in order to determine the effect of two variables; the radial extent of the shoe and the chordwise heat distribution.

The tests were conducted by the AAL at the NACA Ice Research Project, Minneapolis, Minn., during the winter of 1942-43.

EQUIPMENT

The tests were conducted with a thermal-electric blade-shoe and hub-generator combination which was supplied to the U.S. Army Air Forces by the Hamilton Standard Propellers Division of the United Aircraft Corporation, and with two types of blade shoe which were manufactured by the B. F. Goodrich Company.

The Hamilton Standard propeller blade shoes were made of neoprene and molded with internal wire heating elements running radially in the shoes. The heated portion of the blade shoe extended to 50 percent of the blade radius and covered approximately 20 percent of the blade chord. The blade-shoe installation on the propeller of No. 3 engine of the XB-24F airplane is shown in figures 1 and 2. The XB-24F airplane was equipped with an 11-foot, 7-inch-diameter propeller with Hamilton Standard propeller blades No. 6353A-18.

The components of the blade shoes which were manufactured by the B. F. Goodrich Company were arranged with an outer layer of electrically conductive neoprene and an inner layer of neoprene serving as thermal and electric insulator. Two flat, braided copper-wire leads running radially along the edges of the conducting outer layer were fabricated into the blade shoes. The heated portions of the blade shoes extended chordwise approximately to the 20-percent-chord point and radially to 90 percent of the blade radius. The first set of blade shoes manufactured by the B. F. Goodrich Company, designated as blade-shoe type 1, was designed with a uniform radial and chordwise heat distribution. In the second set of blade shoes manufactured by the Goodrich company, designated as shoe type 2, the radial heat distribution was uniform, but in the chordwise direction the heat was concentrated over the leading-edge region (approximately the forward 7 percent of the blade chord) of the blade-shoe area. This heat distribution was obtained by a change in thickness and hence in resistance of the conductive neoprene layer. The blade area protected by the types 1 and 2 blade shoes was the same, and the power inputs to the two types of Goodrich blade shoe were equal at the same line voltage. A Goodrich thermal-electric de-icing blade shoe is shown installed on the propeller of No. 3 engine of an XB-17F airplane in figure 3.

Cross-section diagrams of the three blade-shoe types tested are shown in figure 4.

The hub generator employed with the Hamilton Standard propeller unit had a rated capacity of 750 watts and was manufactured by the General Electric Company. The rotor of the generator was attached to the rear of the propeller hub, while the stator was attached to the front section of the engine crankcase. Field excitation was supplied to the stator from the 24-volt, direct-current, electrical system of the airplane. The power output from the rotor was conducted to the blade shoes of the Hamilton Standard propeller unit by the use of slip rings located at the blade shanks. The hub generator and blade-shank slip-ring covers are also shown in figure 2.

Power was supplied to the types 1 and 2 blade shoes from batteries by a brush and slip-ring assembly shown in figure 5. The types 1 and 2 blade shoes were tested on the propeller of No. 3 engine on an XB-17F airplane at 1010 rpm. The XB-17F airplane was equipped with an 11-foot, 6-inch diameter Hamilton Standard propeller, using blades No. 6477A-0. The power supplied to the blade shoes was computed from measurements of the blade-shoe resistance and of the current supplied during each test. The current in the blade-shoe circuit was measured with a standard aircraft ammeter which was calibrated prior to the tests, and the blade-shoe resistance was measured with a standard bridge circuit-type instrument.

On the basis of the experience gained in the blade-shoe tests, a design output of 2000 watts for a satisfactory hub generator was determined. A hub generator with the new design output (2000 watts) was constructed by the Electric Machinery Manufacturing Company, Minneapolis, Minn., and weighed 29 pounds complete as shown in figures 6 and 7.

TESTS AND RESULTS

In general, the test procedure followed in conducting the research was to fly into the icing region with little or no power supplied to the blade shoes. A given power was supplied for a fixed time, and then the test propeller was feathered and photographed. The procedure was repeated, increasing the power input in each succeeding run.

Figure 8 shows the ice accretions obtained during a flight in icing conditions with the Hamilton Standard propeller de-icing unit supplying full rated power (750 watts at 1150 rpm) to the blade shoes. Figure 8 indicates that neither the capacity of the hub generator nor the radial extent of the blade shoes was sufficient to afford adequate protection against icing.

The tests with the Goodrich type 1 blade shoes at temperatures above 15° F in severe icing conditions indicated that the blades would remain clear of ice at those temperatures. The ice accumulations shown in figures 9 and 10 indicated, however, that the leading edge of this set of blade shoes was not heated sufficiently to remove ice effectively at temperatures below 15° F with a total power input of approximately 2000 watts. The effect of the length of time during which the power was supplied to the type 1 blade shoes was not determined.

The results of tests with the Goodrich type 2 blade shoes are shown in figures 11 to 16. All the tests were run in the same icing condition, which was considered to be of uniform severity. Figure 11 shows the ice accretions on the test propeller on the XB-17F airplane after 18 minutes in the icing condition with no heat supplied to the blade shoes. Figure 12 indicates that a supply of 402 watts to the blade shoe may have been enough to start the ice-removal process, since the ice on the inner portion of the far blade and parts of the ice on the near blade have been thrown off. The location on the near blade at which the ice has been thrown off has started to ice again, indicating that there is some time interval between the shedding of ice on the various portions of the blade. The shank of the far blade is clear, indicating recent de-icing. The condition of the blade leading edge indicates that the total power input to the three blade shoes was too low and allowed excessive ice thicknesses to accumulate before the ice particles were removed. The small flecks of ice just aft of the leading-edge ice accumulation are apparently fixed and do not throw off. A comparison of figures 11 and 12 shows a marked difference in the ice thickness even with as low a total power input as was used in the test shown in figure 12.

A comparison of figures 12 and 13 shows the effect of increasing the total power input to the blade shoes from 402 to 1508 watts. This increase in power input results in the more broken and much thinner ice layer shown in figure 13. The visible area of the lower blade is almost free of ice accumulations, while the upper blade is almost uniformly iced, except at the shank. The near blade appears to be in the intermediate stages of de-icing with some areas lightly iced and others with heavier accretions. The blades will de-ice with the 1508-watt power input, but the ice thickness which accumulates before de-icing is still excessive. Small flecks of ice on the thrust face of the near blade are noted.

Figure 14 shows the results of applying a total power input of 2180 watts for 15 minutes; figure 15 shows the effect of 3100 watts for 6 minutes; and figure 16 shows the result of applying a total power input of 2750 watts for 11 minutes. The results shown in figures 14, 15, and 16 are all similar, which might indicate that the optimum power input had been exceeded. The 2180-watt input (fig. 14), with the type 2 blade shoes, is comparable with the powers used to obtain the results shown in figures 9 and 10 with the type 1 blade shoes. The blades are more satisfactorily de-iced and are protected at lower temperatures with the type 2 blade shoes.

Figure 17 indicates the result of less heating, 840 to 1500 watts, applied for a period of 1 hour. By a comparison of figures 17 and 13, the effect of the length of time of heating on the de-icing effectiveness may be inferred.

DISCUSSION

In the evaluation of the test results, consideration should be given to the factors involved other than the primary variables. The propeller and flight speeds were fixed at the speed for maximum range in all the tests.

If the propeller speed were increased, the output of the hub generator would be increased and the effect of aerodynamic heating probably would become more noticeable. With a change in operating conditions (for instance, assuming those of a pursuit airplane) it is possible that a blade shoe with less radial extent and some variation in the radial heat distribution would be practical. For the reasons just mentioned, it is thought that the tests conducted present a conservative approach to the problem.

Although the heat distribution on the type 2 blade shoes produced satisfactory results, it should not be concluded that this represents the optimum distribution. In view of the possibility of obtaining greater protection with a given quantity of heat, an analytical study of the heat-distribution problem should be undertaken. Until such an analysis is made, and checked by experiment, it is suggested that a minimum average unit power of 2.5 watts per square inch of blade-shoe area be used in future designs which are similar to those tested. This heat quantity is based on the fact that, in normal operation, the heating time will be protracted.

CONCLUDING REMARKS

The tests indicate that the final design of blade shoe tested (type 2) and the 2000-watt hub-generator combination will de-ice the test propeller blades in icing conditions similar to those encountered and should, after service tests, provide an acceptable means of propeller de-icing.

Pending further tests, the following design principles are recommended:

1. A minimum average unit power input of 2.5 watts per square inch of blade-shoe area should be provided for blade shoes covering the leading-edge 20-percent chord and 90 percent of the blade radius.

2. The heat distribution should be such that the unit heating supplied to the leading-edge 7-percent chord is twice that supplied to the remainder of the blade-shoe area.

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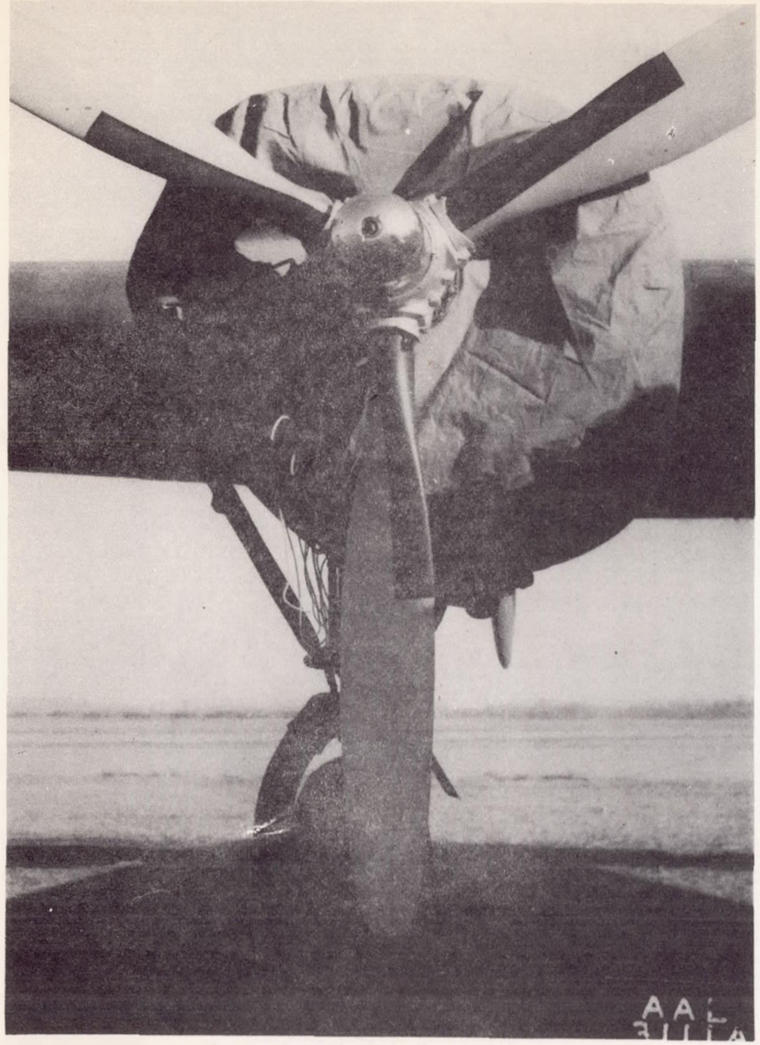

Figure 1.- The Hamilton Standard Propeller de-icing unit installed on the XB-24F airplane.

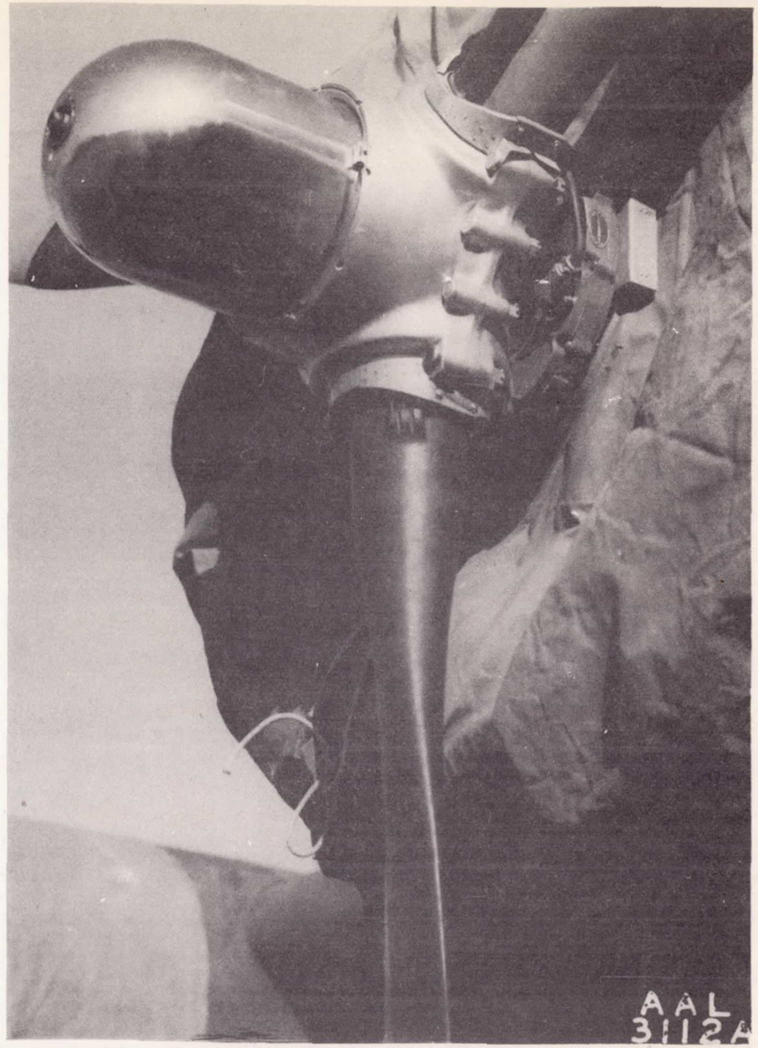

Figure 2.- The Hamilton Standard Propeller de-icing unit on the XB-24F airplane showing the hub generator, blade shank slip-ring assemblies, and the heated blade shoes.

Figure 3.- A B.F.Goodrich Company thermal electric de-icing blade shoe installed on a propeller blade of XB-17F airplane.

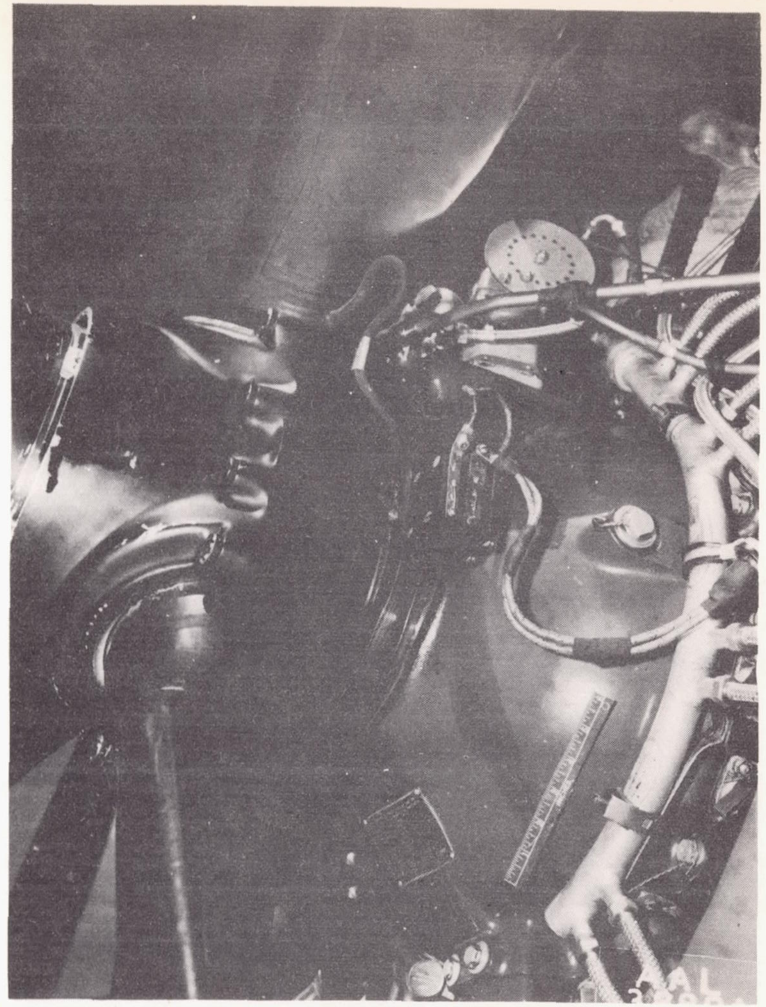

Figure 5.- The brush and slip-ring assembly for conducting electric power to the blade shoes as installed on an engine of the XB-17F airplane.

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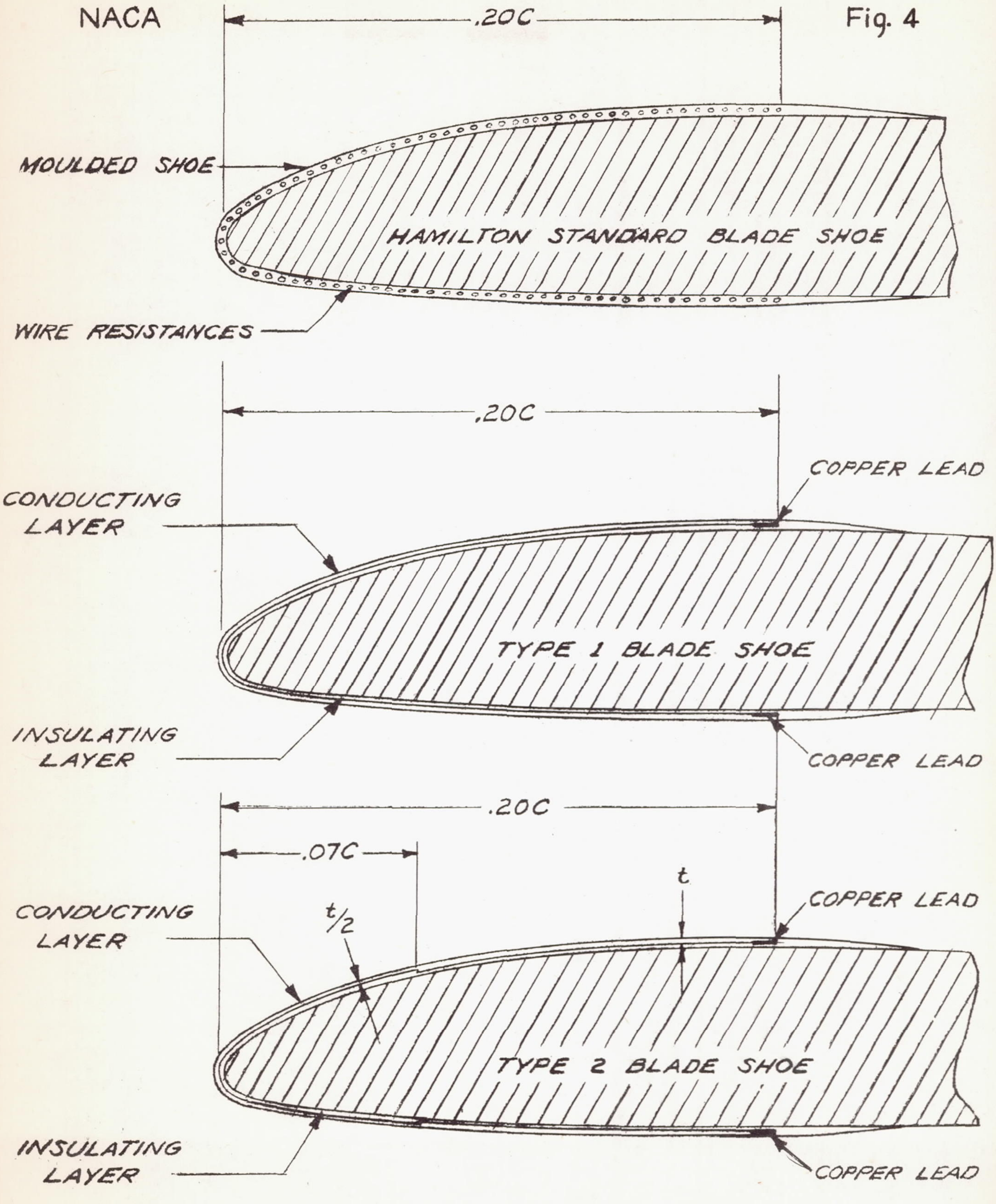

FIGURE 4. – SECTIONS OF THE BLADE SHOES TESTED.

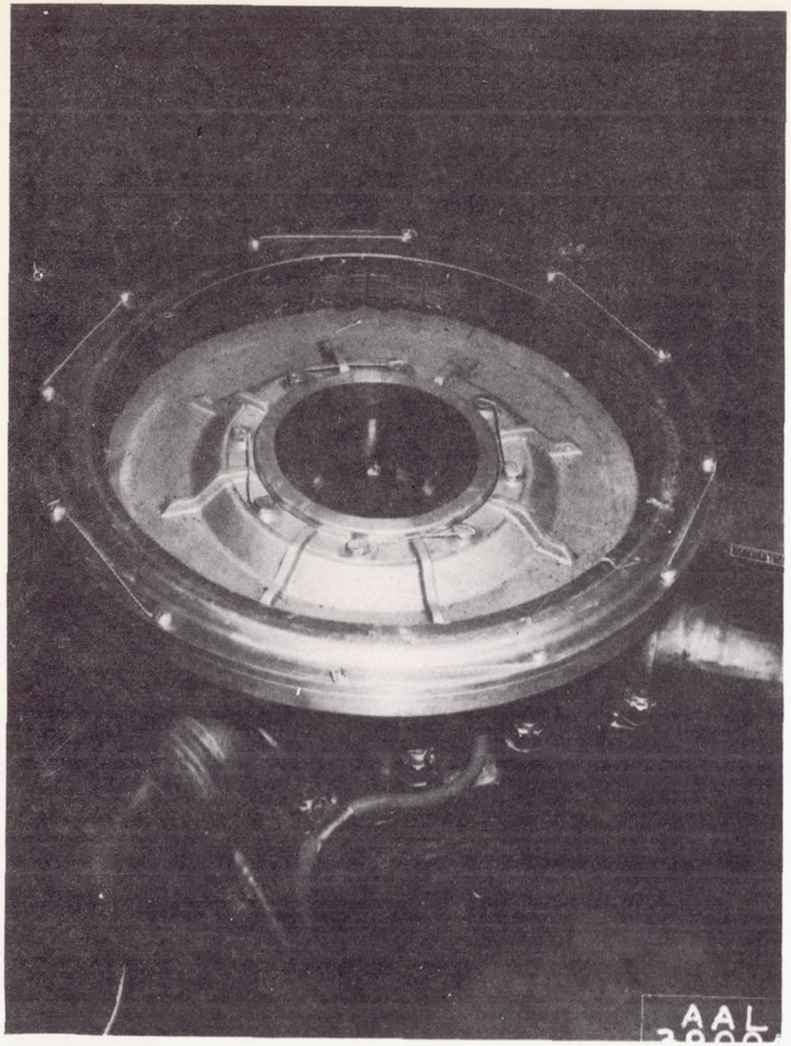

Figure 6.- The rotor for a 2000-watt hub-generator installed on a propeller of the XB-17F airplane.

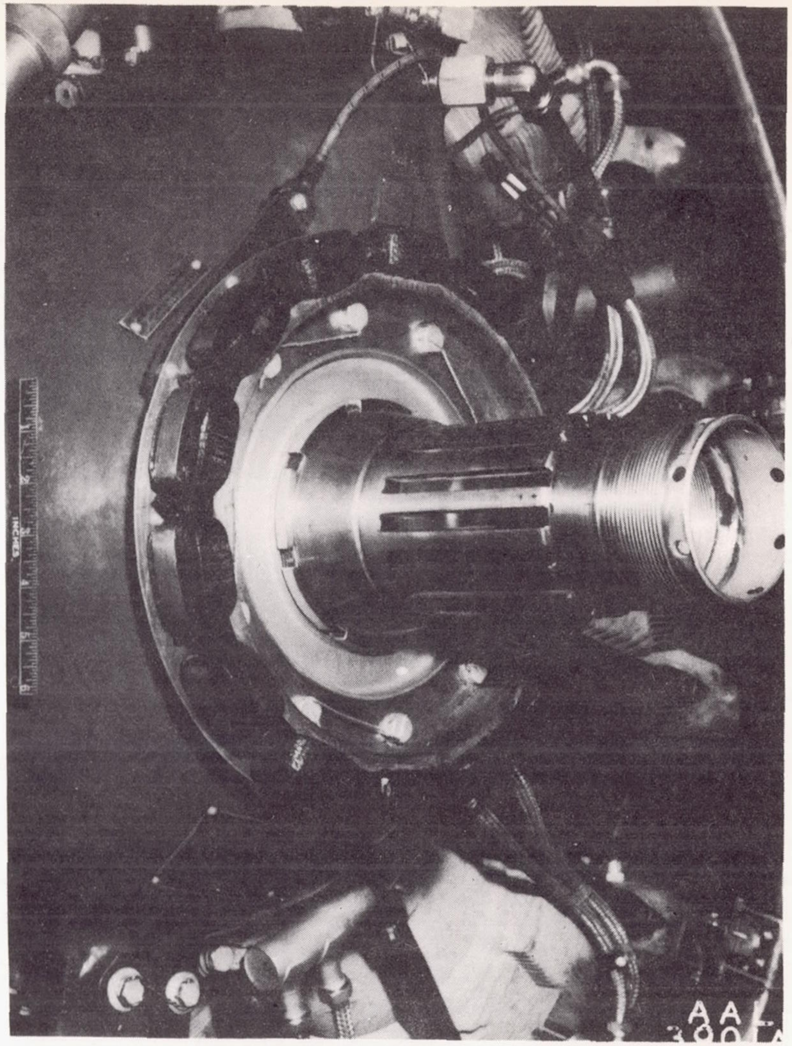

Figure 7.- The stator for a 2000-watt hub-generator installed on an engine of the XB-17F airplane.

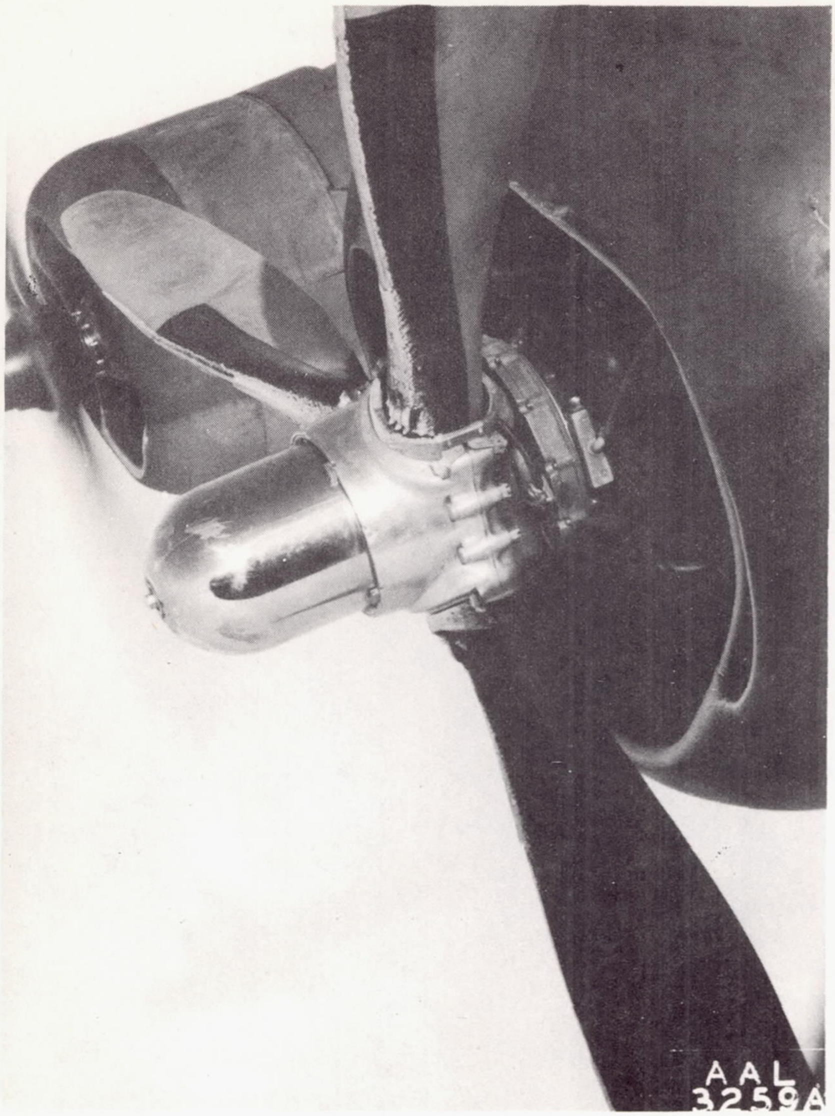

Figure 8.- Ice formations on the thermal-electric de-icing blade shoes of the Hamilton Standard Propeller Unit installed on the XB-24F airplane.

Date:	January 2, 1943	Airspeed:	180 mph
Ambient air temp.:	14° F	Propeller speed:	1150 rpm
Altitude:	4000 ft	Manifold pressure:	32 in. Hg
Type of ice:	light rime	Total power input:	750 watts

Average unit power: approx. 1.4 watts/sq in.

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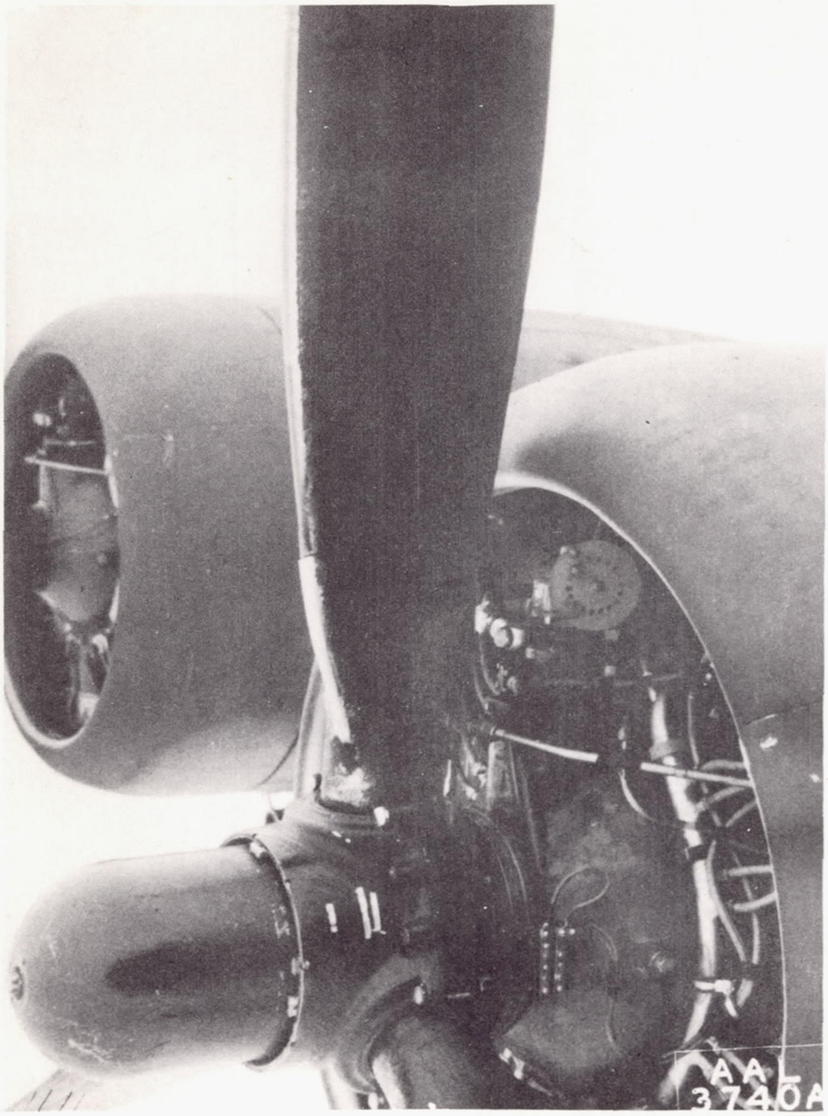

Figure 9.- Ice formations on the thermal-electric de-icing blade shoes installed on a propeller of the XB-17F airplane.

Date:	March 3, 1943	Shoe type:	1
Indicated airspeed:	200 mph	Propeller speed:	1140 rpm
Pressure altitude:	5000 ft	Total power input:	2080 watts for 9 minutes
Ambient air temp.:	7° F	Average unit power:	2.77 watts/sq in.
Type of icing:	light rime		

Unit power to shoe leading edge: 2.77 watts/sq in.

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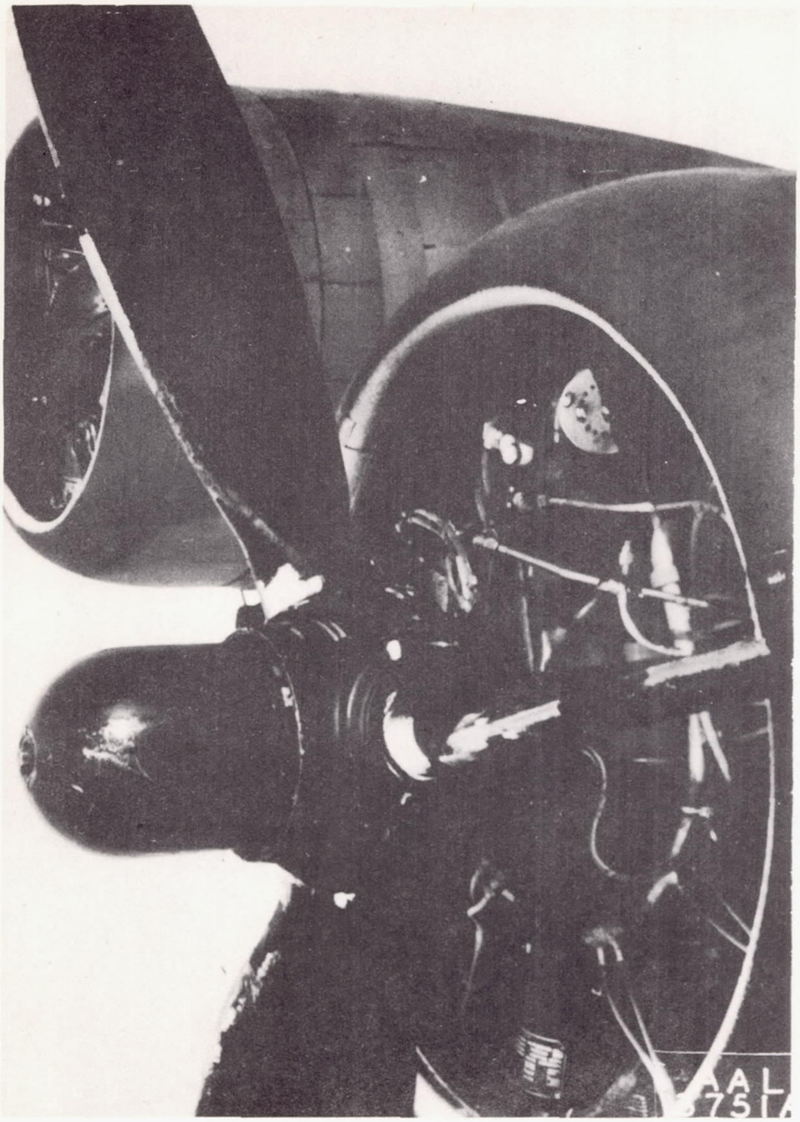

Figure 10.- Ice formations on the thermal-electric de-icing blade shoes installed on a propeller of the XB-17F airplane.

Date: March 4, 1943
Indicated airspeed: 175 mph
Pressure altitude: 5,600 ft
Ambient air temp.: 10° F
Type of ice: rime

Shoe type: 1
Propeller speed: 1010 rpm
Total power input: 1975 watts for ten minutes
Average unit power: 2.63 watts/sq in.

Unit power to shoe leading edge: 2.63 watts/sq in.

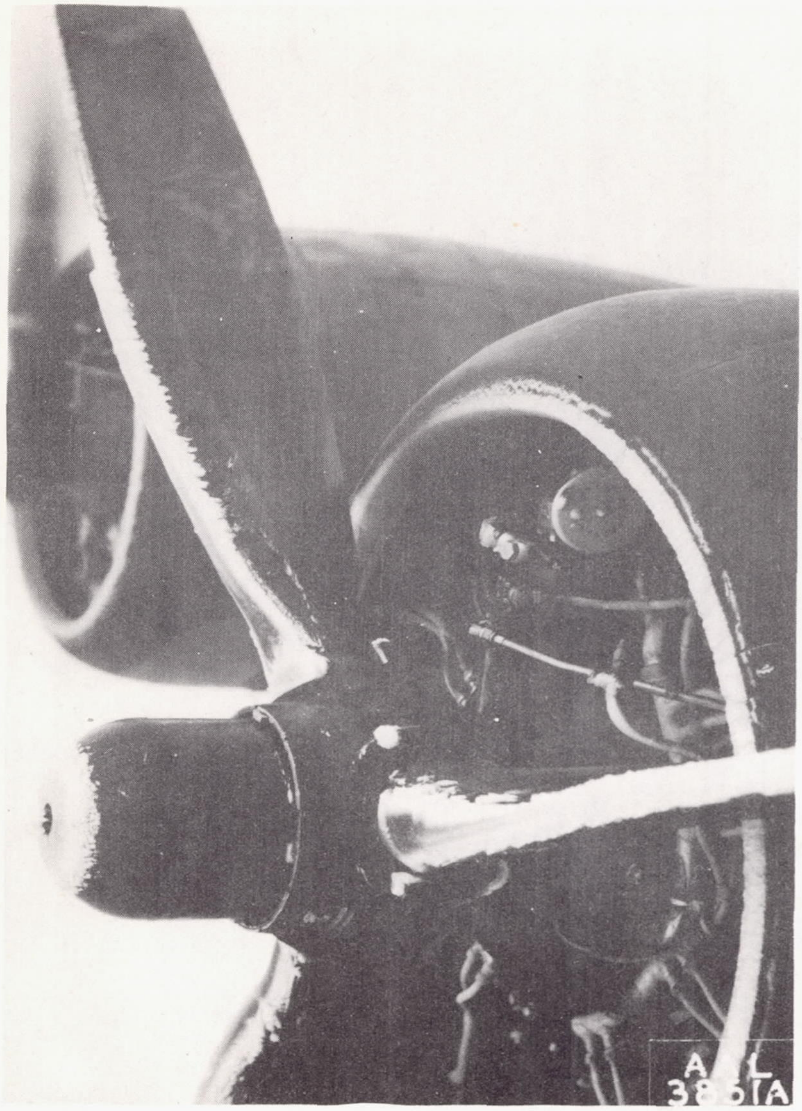

Figure 11.- Ice formations on the thermal-electric de-icing blade shoes installed on a propeller of the XB-17F airplane.

Date: March 27, 1943
Indicated airspeed: 160 mph
Pressure altitude: 10,000 ft
Ambient air temp.: 9° to 11° F
Type of ice: rime

Shoe type: 2
Propeller speed: 1010 rpm
Total power input: none for 18 minutes
Average unit power: none
Unit power to the shoe leading edge: none

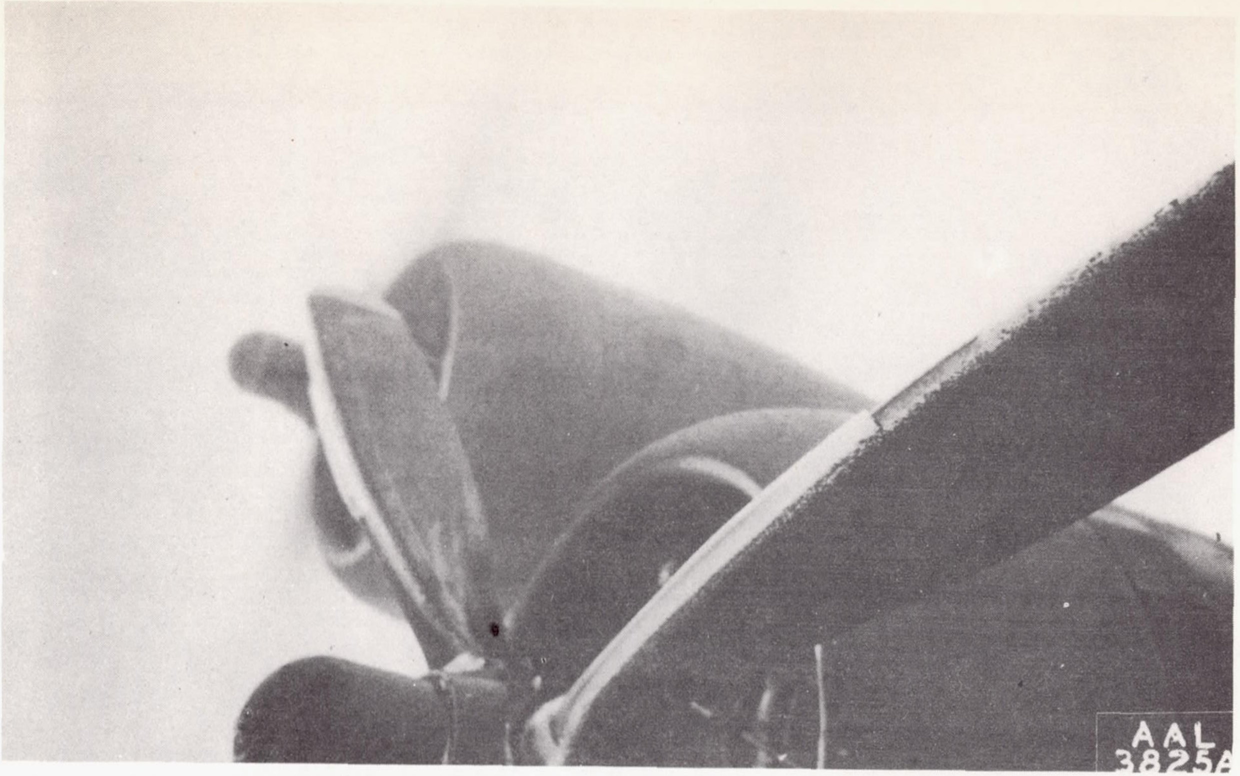

Figure 12.- Ice formations on the thermal-electric de-icing blade shoes installed on a propeller of the XB-17F airplane.

Date: March 27, 1943
Indicated airspeed: 160 mph
Pressure altitude: 10,000 ft
Ambient air temp.: 9° to 11° F
Type of ice: rime
Shoe type: 2
Propeller speed: 1010 rpm
Total power input: 402 watts for nine minutes
Average unit power: 0.53 watts/sq in.
Unit power to shoe leading edge: 0.79 watts/sq in.

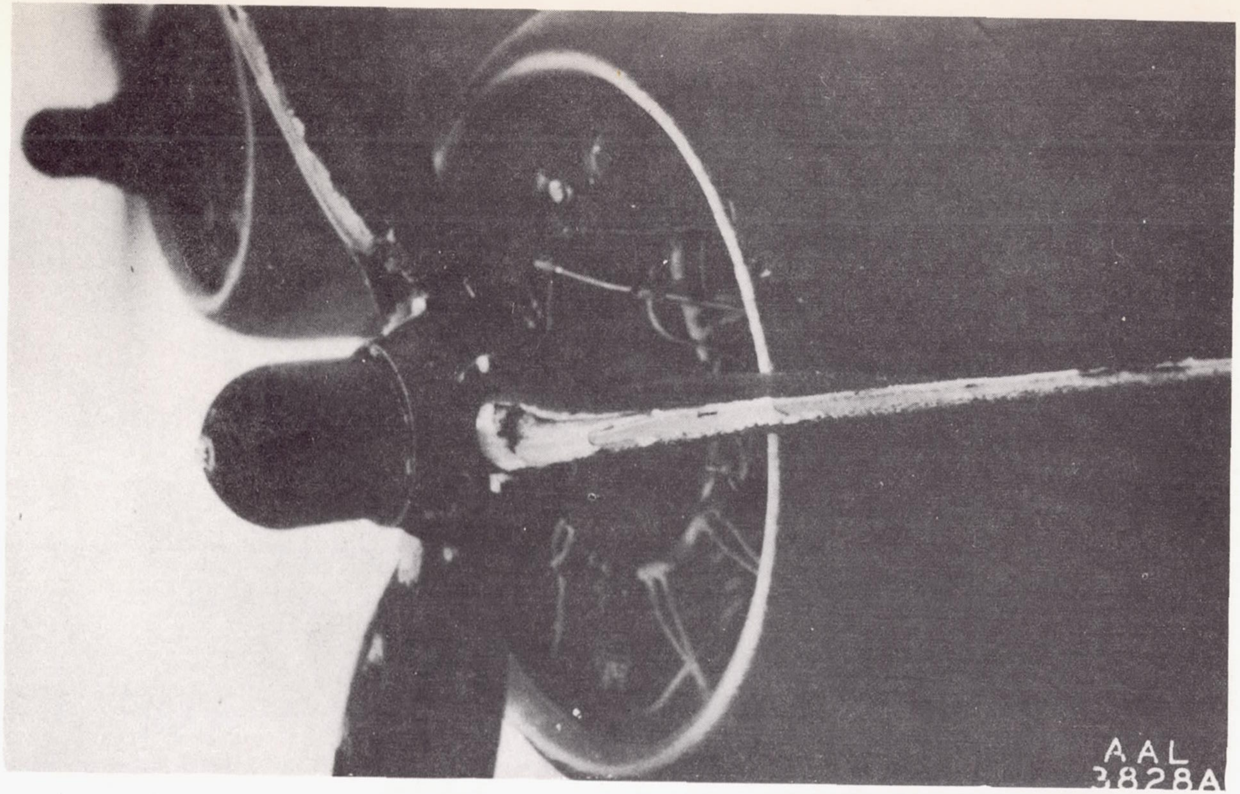

Figure 13.- Ice formations on the thermal-electric de-icing blade shoes installed on a propeller of the XB-17F airplane.

Date: March 27, 1943
Indicated airspeed: 160 mph
Pressure altitude: 10,000 ft
Ambient air temp.: 9° to 11° F
Type of ice: rime

Shoe type: 2
Propeller speed: 1010 rpm
Total power input: 1508 watts for eleven minutes
Average unit power: 2.00 watts/sq in.

Unit power to shoe leading edge: 3.00 watts/sq in.

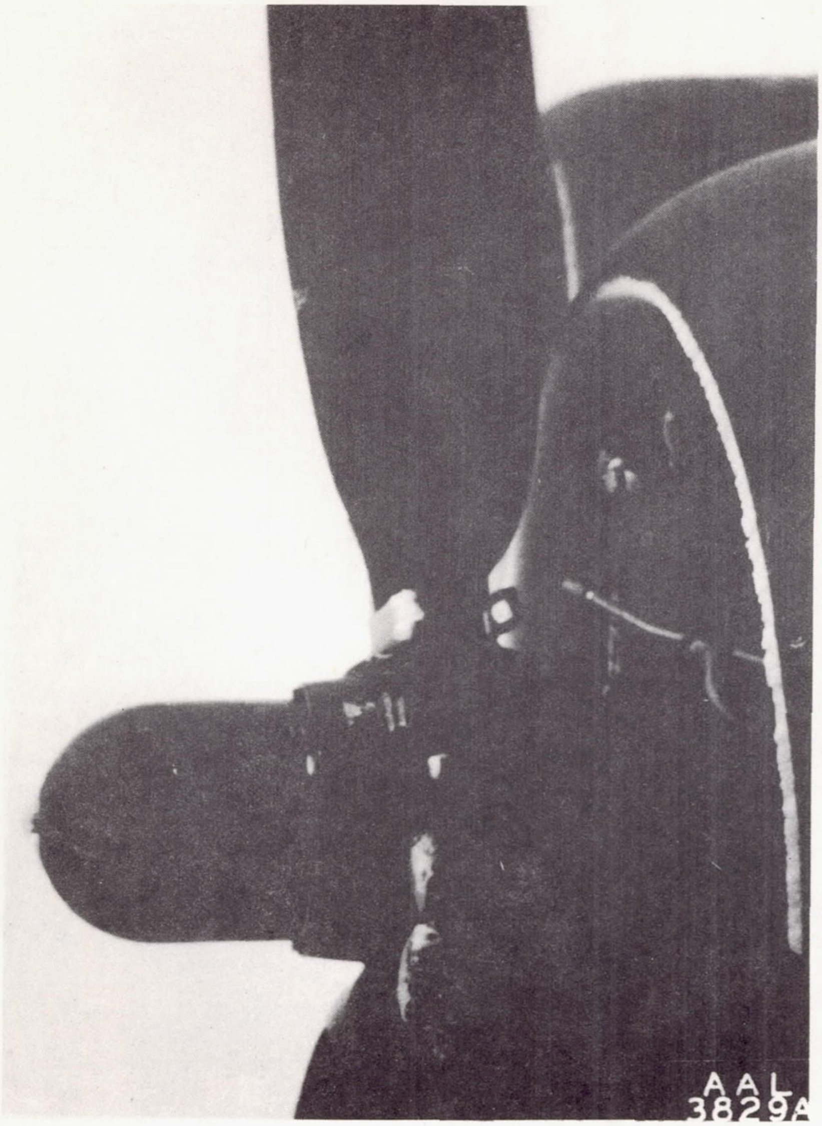

Figure 14.- Ice formations on the thermal-electric de-icing blade shoes installed on a propeller of the XB-17F airplane.

Date: March 27, 1943
Indicated airspeed: 160 mph
Pressure altitude: 10,000 ft
Ambient air temp.: 9° to 11° F
Type of ice: rime
Shoe type: 2
Propeller speed: 1010 rpm
Total power input: 2180 watts for 15 minutes
Average unit power: 2.90 watts/sq in.
Unit power to shoe leading edge: 4.35 watts/sq in.

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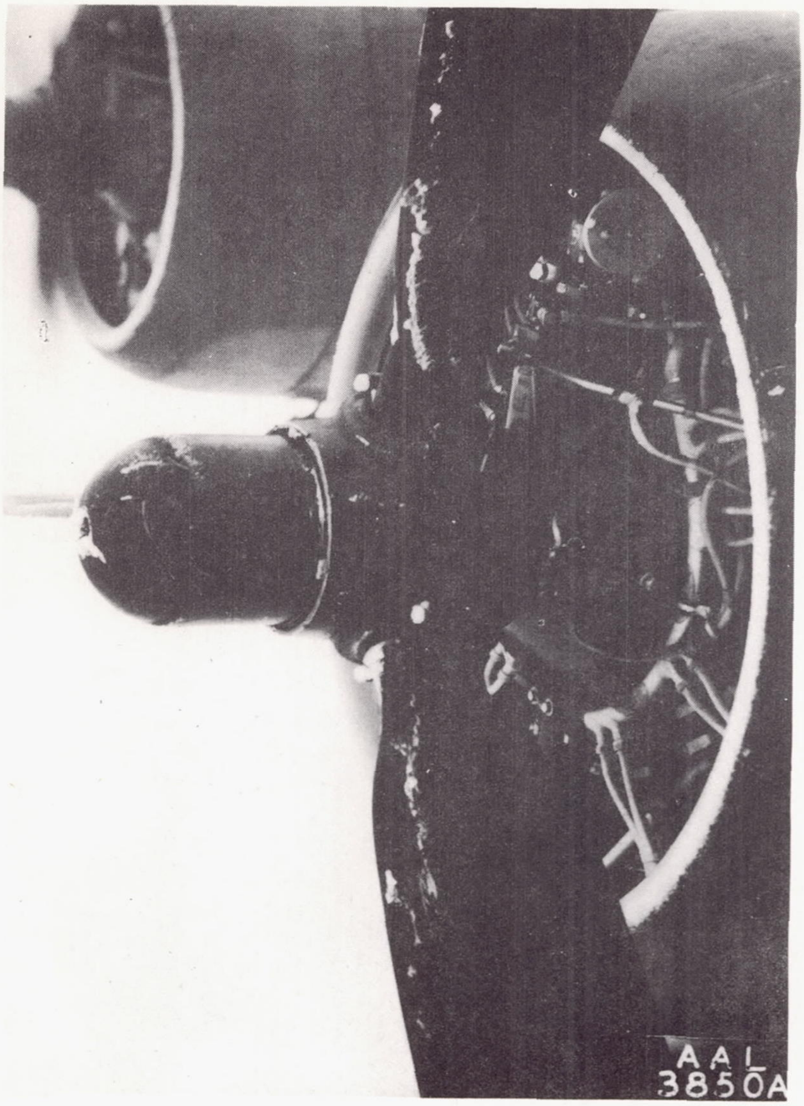

Figure 15.- Ice formations on the thermal-electric de-icing blade shoes installed on a propeller of the XB-17F airplane.

Date: March 27, 1943
Indicated airspeed: 160 mph
Pressure altitude: 10,000 ft
Ambient air temp.: 9° to 11° F
Type of ice: rime

Shoe type: 2
Propeller speed: 1010 rpm
Total power input: 3100 watt for six minutes
Average unit power: 4.12 watts/sq in.

Unit power to the shoe leading edge: 6.18 watts/sq in.

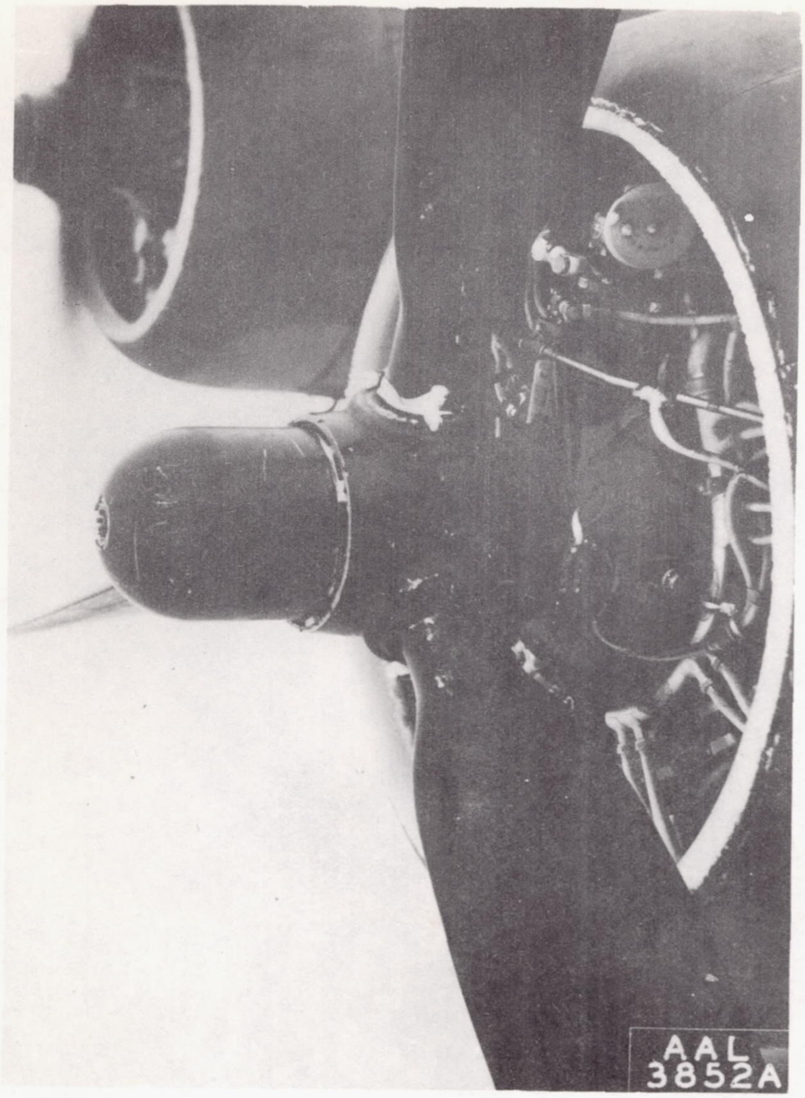

Figure 16.- Ice formations on the thermal-electric de-icing blade shoes installed on a propeller of the XB-17F airplane.

Date: March 27, 1943
Indicated airspeed: 160 mph
Pressure altitude: 10,000 ft
Ambient air temp.: 9° to 11° F
Type of ice: rime
Shoe type: 2
Propeller speed: 1010 rpm
Total power input: 2750 watts for 11 minutes
Average unit power: 3.66 watts/sq in.
Unit power to the shoe leading edge: 5.48 watts/sq in.

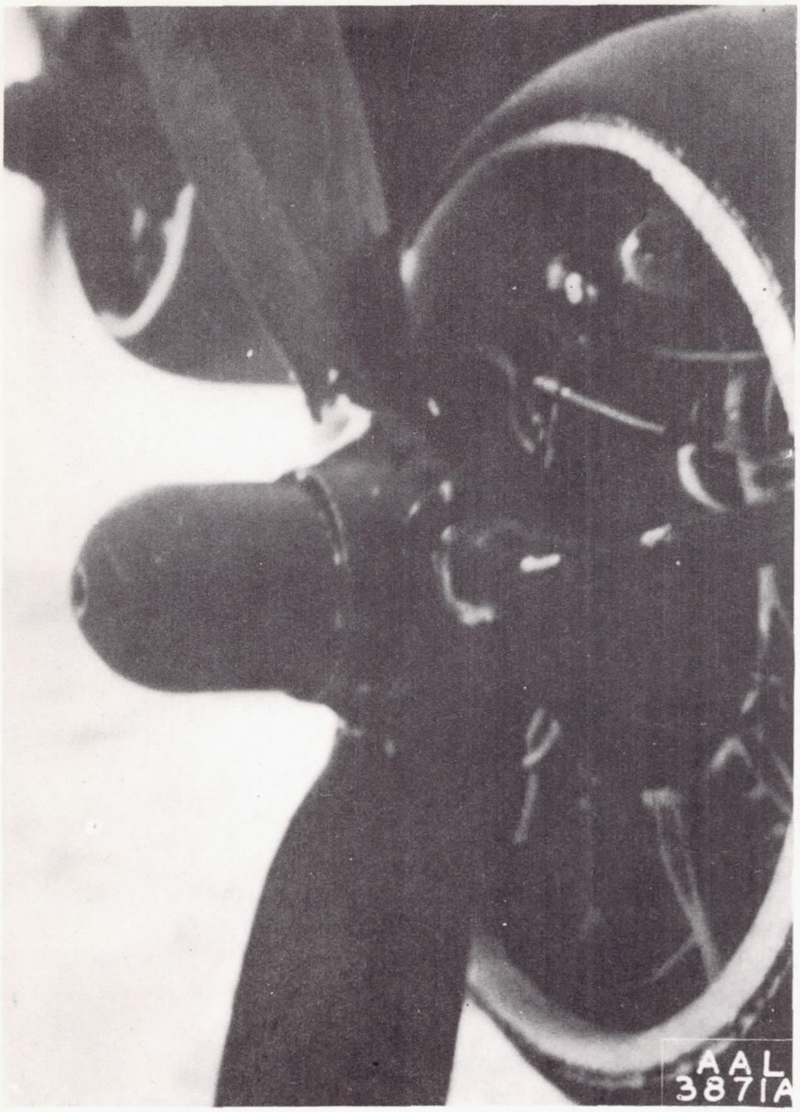

Figure 17.- Ice formations on the thermal-electric de-icing blade shoes installed on a propeller of the XB-17F airplane.

Date: March 27, 1943
Indicated airspeed: 160 mph
Pressure altitude: 9,000 to 10,000 ft
Ambient air temp.: 9° to 14° F
Type of ice: rime
Unit power to the shoe leading edge: 3.00 to 1.68 watts/sq in.

Shoe type: 2
Propeller speed: 1010 rpm
Total power input: 1500 to 840 watts for 60 minutes
Average unit power: 2.0 to 1.12 watts/sq in.