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FLIGHT TESTS OF THERMAL ICE-PREVENTION EQUIPMENT IN THE XB-24F AIRPLANE

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WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Materiel Command, U. S. Army Air Forces

FLIGHT TESTS OF THERMAL ICE-PREVENTION EQUIPMENT IN THE XB-24F AIRPLANE

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SUMMARY

Performance tests of thermal ice-prevention equipment designed and installed in the XB-24F airplane by the Ames Aeronautical Laboratory of the National Advisory Committee for Aeronautics have been conducted in icing and non-icing conditions. The non-icing tests were performed at the AAL, Moffett Field, Calif. The icing tests were undertaken as a part of the NACA Ice Research Project, Minneapolis, Minn., in conjunction with the Materiel Command of the Army Air Forces and the Northwest Airlines, Inc.

In general, the performance tests consisted of level flights at cruising power during which temperature observations were made of the heated circulating air, the airplane surfaces exposed to ice formations, and, at a few locations, the internal structure of the airplane. The rate of flow of the circulating air was also determined. For the flights in icing conditions, observational, and photographic data of the susceptibility of the protected and unprotected areas of the airplane to ice formations were obtained. A few tests were made of the ability of the equipment to remove frost and ice from the wing outer panels and the windshield prior to flight.

The recorded temperature and air-flow data, and the calculated quantities of heat flow throughout the system are presented in tabular form. Photographs showing performance of the equipment under natural icing conditions, and typical ice formations on unprotected components of the airplane are presented.

The test results indicate that the equipment was adequate, with a few exceptions, to prevent ice formation on the surfaces for which protection was desired. Further development of the heat-exchanger installation and circulating air supply system to reduce the restrictions to air flow, and thus realize more of the available heat-exchanger capacity, is recommended.

The tests demonstrated that the performance specification for the installation was satisfactory, and should prove entirely adequate

for any similar future installation. Sufficient data are available to prepare a design which will meet the performance specification, and be structurally satisfactory from a stress and a production standpoint.

INTRODUCTION

A study of the problems involved in providing thermal ice-prevention equipment for aircraft has been conducted by the NACA under a general program of ice-prevention research. The first tests were conducted on model wing sections, and the same principle was later applied to provide a thermal ice-prevention system on a Lockheed 12A airplane (reference 1). In 1942 a design similar to that described in reference 1 was prepared for the B-24D airplane in cooperation with the Materiel Command of the Army Air Forces, the Consolidated Aircraft Company, and several equipment manufacturing companies. Reference 2 describes the design and construction of this installation and the instrumentation provided for performance tests. The performance specification adopted for the design required an average temperature rise of 100° F for the wing and empennage surfaces forward of the 10-percent-chord point.

This report presents the results of performance tests of the XB-24F airplane thermal ice-prevention installation. Preliminary tests consisted of ground runs and flights under dry air (no visible moisture) conditions. Slight alterations to the equipment were made as a result of these investigations, and the installation was then tested under natural icing conditions.

The tests of the equipment in dry air were conducted at the AAL at Moffett Field, Calif. The tests in natural icing conditions were conducted as a part of the NACA Ice Research Project at Minneapolis, Minn., the facilities and services of which were supplied by the Northwest Airlines, Inc., acting under a directive from the Air Transport Command of the Army Air Forces. The airplane was piloted by AAF and Northwest Airlines personnel who had previous extensive experience in the operation of transport aircraft in icing conditions. A meteorologist from the U. S. Weather Bureau was assigned to the Project to assist in the preparation of weather forecasts, to analyze and correlate the atmospheric data obtained, and to prepare reports concerning the meteorological aspects of the icing investigations.

DESCRIPTION OF EQUIPMENT

The XB-24F airplane is shown in figure 1. A description of the thermal ice-prevention equipment for the airplane is given in reference 2, and the general arrangement drawing of the equipment (fig. 2) is taken from that reference.

With a few exceptions, the ice-prevention equipment for the performance tests reported herein was identical to that described in reference 2. The exhaust-gas-to-air heat exchangers described in reference 2 were replaced by pin-fin-type units. The heat exchanger for one of the nacelles is shown in figure 3. The main shell and inner fins consisted of a single sheet of stabilized stainless steel, folded longitudinally to form the inner fins and welded at the seam and fin ends. The outer pins were formed by cutting slots in 2-inch-wide by 0.040-inch-thick copper strips. The slots were 3/32 inch wide, 1-3/16 inches deep, and were spaced to form pins 1/16 inch wide. The solid portion of the strips was inserted between the folds forming the inner fins and was furnace-brazed to the stainless steel. Alternate outer pins were staggered to double the number of longitudinal rows. Preliminary tests of the exchangers in flight (not included in this report) indicated that the pressure drop across the air side was too large, and therefore some of the outer pins were removed. The configurations of the exchangers and shrouds which apply to all the tests of this report are shown in figure 4.

The air-intake scoops for the dry-air flights were the same as those shown in figure 17 of reference 2, which also shows the exchanger installation. For the flights in icing conditions, the intake scoops were altered slightly to provide for heating of the leading edges as a protection against ice formation. During the flight-test period at Minneapolis other minor changes were made to the equipment in an attempt to correct the performance of parts that did not give satisfactory protection from ice formation.

The windshield design shown in figures 14 and 15 of reference 2 employed plastic inner and outer panels. After several preliminary flights the outer panel was replaced with laminated safety glass, and the installation was tested in this form during all of the non-icing flights, and some of the icing flights, herein reported. During the icing flights, the inner panel was replaced with 3/8-inch-thick laminated safety glass and a blower was installed in the windshield heated-air supply duct, figure 5. Installation difficulties encountered with the flat glass inner panel resulted in an air gap that was irregular, and larger than that desirable for thermodynamic reasons. An arrangement to cause all of the windshield heated air to flow through the pilot's windshield was provided by the installation of a butterfly valve in the supply duct to the copilot's windshield.

The locations of thermocouples and pressure orifices used for obtaining the performance data are shown in figures 6 and 7. The types of thermocouple and pressure-orifice mountings are shown in figures 26 and 28 of reference 2. In order to determine the accuracy of the thermal installations, a laboratory investigation was conducted in which the thermocouples were subjected to conditions simulating those existing during the performance tests of the ice-prevention equipment. The tests showed that the thermocouples indicating air temperatures were subject to a maximum error of $\pm 3^\circ$ F, and those indicating skin-surface temperatures to errors from 0° to 8° F. All thermocouples were iron-constantan and the temperature indications were obtained with a direct-reading potentiometer. All pressures were referred to the total pressure of the left airspeed head at the airplane nose. Pressure differentials were indicated by water manometers and airspeed indicators for the dry-air flights, and by a single airspeed indicator for the icing flights. Free-air temperature, indicated airspeed, altitude, and engine data were obtained from the service instruments on the pilot's panel. The static pressure indication of the airspeed installation was calibrated with a suspended trailing static head to provide a basis for correct indicated airspeed.

For the initial windshield arrangement (plastic inner and outer panes), thermocouples were installed in the surfaces of the inner and outer panes and in the air entrance and exit headers of the copilot's windshield. A venturi meter was placed in the copilot's windshield air duct to measure the flow of air to the windshield. When the plastic panels were replaced by safety glass, the surface thermocouples were omitted because of the difficulties encountered in installing them in the glass surfaces. No means of obtaining temperatures or air flows were provided for the pilot's windshield.

TEST PROCEDURE

The flight tests in non-icing conditions consisted of level flights at approximately cruising power, and at pressure altitudes of 10,000 and 18,000 feet. Heated air from the exchangers was directed to the various components of the ice-prevention system, a few temperature indications were observed until thermal equilibrium had been established, and then complete temperature and pressure data were recorded. In order to provide data for an estimation of the frost-removal capabilities of the installation, the flight tests were supplemented by a ground run in which the right outboard engine was operated at idling conditions and temperatures were recorded for the wing outer panel.

The flight tests in natural icing conditions at the Ice Research Project were planned with the cooperation of the U. S. Weather Bureau and the Northwest Airlines dispatch office. After determining the location of the icing condition, a preliminary vertical and horizontal traverse was made to define the icing region and determine the severity of the icing condition. The airplane was then flown in the icing region and all exposed parts of the airplane, protected and unprotected, were observed.

Temperature data were obtained during icing conditions, and photographs were taken showing ice formation or prevention on exposed surfaces. For each flight an attempt was made to land with ice accumulations on unprotected or insufficiently heated parts in order that the formations might be photographed and studied. During two flights in icing conditions the heat to the wing outer panels was turned off, thus allowing ice to form, and observations were made of the removal of the ice accretions when the heat was again applied. Ground observations were made of the ability of the system to remove frost, snow, and ice from the wing outer panels with the engines in the idling condition.

RESULTS

The data recorded during the tests of the XB-24F airplane in dry air are presented in tables I to IV. The thermocouple and pressure orifice numbers given in the tables correspond to those shown in figures 6 and 7.

Calculations based upon the data in tables I to IV show that the average temperature rise of the wing outer-panel leading-edge skin, above ambient air, for cruising flight at 18,000 feet (design conditions) was approximately equal to the design value of 100° F. The leading-edge skin is defined as the heated area forward of the 10-percent-chord point. The greatest deviation from the average value occurred at the center of the semispan, at which point an average rise of 80° to 90° F was observed. Sufficient data were not obtained to permit comment on the chordwise temperature distribution.

The change in air temperature in passing through the leading-edge corrugation passages varied from about 140° F near the inboard end of the outer panel to 80° F near the wing-tip joint at both of the test altitudes. An estimation of the heat flow through the leading-edge skin, calculated from the air-flow rate and the average temperature change in passing through the corrugation passages, resulted in a value of 30,000 Btu per hour (725 Btu per hr per sq ft of leading-edge surface) for the tests at the design altitude. The heated air circulating inside the wing after discharge from the leading-edge system transferred approximately 30,000 Btu per hour to the wing skin and structure before leaving the wing at the aileron gap.

The average temperature rise of the wing inboard panel leading-edge skin in the dry-air flights was approximately 95° F near the inboard nacelle and 75° F near the outboard nacelle, or an over-all average of 85° F. The change in temperature of the air in flowing through the corrugation passages was 200° F (inboard) and 130° F (outboard). Based on average temperatures of the circulating air before and after passing through the leading-edge system, and the rate of air flow, the heat flow through the skin surface was about 20,000 Btu per hour, or 750 Btu per hour per square foot of leading-edge surface.

The temperature rise of the horizontal stabilizer leading-edge skin in dry air varied from 35° F inboard to 95° F at the fin, or an average rise of 65° F. The heat flow through the empennage leading-edge surfaces could not be calculated because the distribution of the air flow to the various components was not determined. The average temperature rise of the fin leading-edge skin was about 50° F, the average at the top of the fin being 15° F above that at the bottom. No thermocouples were located in the central portion of the fin leading edge, which appeared to be the coldest area, based on ice-formation observations.

No thermal data for the windshield are presented for the following reasons: The preliminary flights with the initial installation indicated that the thermal conductivity of the plastic outer panel was excessively low, and hence the panel was replaced with the higher conductivity material, glass. The dry-air flights for this arrangement provided data of the heat loss of the circulating air in the copilot's windshield; but these data, to be of design use, must be correlated with outer-surface temperature rise or actual icing tests. During the icing flights most of the heated air was directed to the pilot's windshield to provide complete protection for that side and, as a result, some ice formed on the copilot's windshield due to an insufficient quantity of heated air. Since no provision was made for obtaining temperatures or air-flow rates for the pilot's windshield, only observational data were obtained.

Observations were made on 17 flights in icing conditions, during which icing was encountered for a total elapsed time of approximately 9-1/2 hours. The icing conditions encountered include rime ice at temperatures as low as -3° F, freezing rain at temperatures as low as 15° F, and glaze ice over a range of temperatures from 20° F to 32° F. The data recorded during the flights in icing conditions are presented in tables V to VIII. Based on the data in these tables, the average temperature rise of the wing outer-panel leading-edge skin was approximately 90° F, and the average heat flow through that surface was about 850 Btu per hour per square foot. Photographs taken during flights in icing conditions, and immediately after landing, showing ice accumulations on unprotected and insufficiently heated parts are presented in figures 8 to 28.

A map of the region in which the icing tests were made, including the locations listed in table V is given as figure 29.

The leading edges of the wing outer panels were maintained free from ice formations in all tests when the heated air was applied to those surfaces prior to entering the icing condition, and were cleared in less than two minutes after heat had been applied during the test of the ice-removal characteristics. Under some atmospheric conditions, during both the ice-prevention and the ice-removal tests, ice formations on the lower surface of the wing, formed from water running aft from the heated leading edge, were observed. This condition was photographed after tests 7 and 8, and is shown in figure 8. Ice accretions shown on the wing leading edge in figure 8 formed after the heat supply to the wing outer panel had been discontinued to preserve the ice formations on the under surface. The upper surface of the wing outer panels and the aileron and flap hinge regions were maintained free from ice formations under all conditions. Ice formed on the leading edges of the wing tips in all of the test conditions. (See fig. 9.)

Complete protection of the leading edge of the wing inboard panel was not obtained under most icing conditions with the engines at cruising power. (See fig. 10.) Ice formations similar to those shown in figure 10, however, were removed in one test by increasing the engine manifold pressure 2 to 4 inches of mercury above cruising conditions. From data in table VII, the average heat flow through the skin forward of the front spar was calculated to be approximately the same as that obtained in dry-air flights, or about 750 Btu per hour per square foot of surface area. No ice was observed to form on the upper surface of the wing inboard panel aft of the leading edge, but ice did form on the lower surface in some tests, as shown in figure 10.

In general, protection for the leading edge of the horizontal stabilizer was provided in all flights with the exception of small areas at the stabilizer root and tip. In one flight at a temperature of -3° F, incomplete protection of the leading edge was evidenced as shown in figure 11. Ice formations at the inadequately heated root and tip areas are shown in figures 12 and 13. The average temperature rise of the leading-edge skin during all of the icing conditions was approximately 40° F.

Ice formations aft of the leading edge on the under surface of the horizontal stabilizer were observed in some flights and are shown in figures 14 and 15. Ice was not observed to form at any time in the vicinity of the elevator hinges or on the elevator surfaces, which were not heated. In most of the flights ice formed on the central portion of the fin leading edge, the top and bottom sections remaining clear (figs. 15 and 16). An attempt was made to improve the heating of the central region by reducing the internal obstruction to air flow in that vicinity, but only slight improvement was obtained. In the test flight at an air temperature of -3° F, ice formed along the entire fin leading edge as shown in figure 11. In test 12 the central portion of the leading edge (shown covered with an ice formation during flight at cruising power in fig. 15) was maintained in an intermittently cleared condition by operating the engines at a manifold pressure about 4 inches of mercury above the cruising condition. The two points in the leading edge at which the outer skin overlapped were seldom cleared of ice formations.

The average temperature rise of the fin leading-edge skin during the icing flights was approximately 45° F. Attention is again directed to the fact that this average value is based upon temperature data from thermocouples located in the cleared regions, and may not be representative of the entire leading-edge surface.

In some of the test flights, slight ice formations were observed on the sides of the fins aft of the leading edge, as shown in figures 14 and 17. The rudder hinges and surfaces, which were not heated, were observed to be clear of ice at all times.

Frost, snow, and ice were removed from the leading edge of the wing outer panel at air temperatures as low as 6° F during ground tests by operating the outboard engines at idling conditions. Frost was removed from the wing surface aft of the leading edge over areas where the circulation of the heated air was not blocked by internal obstructions such as gas tanks.

In one ground test in which the entire wing was covered with a thick ice formation produced by a freezing rain, the forward 20 percent of the wing outer-panel surface was cleared in 15 minutes, but the melted ice refroze aft of the cleared area and no formations behind the region were removed.

During the first flight tests in icing conditions the inner plastic panels of the heated windshield buckled due to thermal expansion, resulting in a much larger gap between the two panes than was desired for thermodynamic reasons and causing considerable distortion of vision.

With the final windshield arrangement (glass inner panel, blower in the windshield supply duct, and shut-off valve in copilot's supply duct) ice was prevented from forming on the pilot's windshield during all icing conditions encountered. For the copilot's windshield the degree of protection afforded varied during the tests, being dependent upon the heated air available after the pilot's windshield had been supplied. Figures 18 and 19 show the pilot's and copilot's windshields during a typical icing flight. Frost on the exterior and interior of the pilot's and copilot's windshields, which had formed with the airplane at rest, was readily removed by the heated-air system during ground warm-up.

During all of the icing conditions encountered, the electrically heated pitot-static airspeed head was maintained free from ice accumulations. Formations occurred on the airspeed mast, however, which may have been of sufficient magnitude to affect the airspeed indicator and altimeter readings. (See fig. 20.) Accordingly, a second source of static-pressure reference was established, which consisted of two interconnected static orifices flush-mounted on opposite sides of the fuselage about midway between the trailing edge of the wing and the leading edge of the stabilizer. An airspeed indicator was connected to the static pressure from these fuselage vents and to an electrically heated total head located at the nose of the airplane. This installation gave reliable airspeed readings under all conditions encountered.

For the flights in icing conditions the service radio antenna was replaced with a 1/16-inch steel cable which was rubber-covered to reduce radio static interference. With the exception of occasional precipitation static interference, radio reception was maintained during all of the flights in icing conditions irrespective of heavy ice formations on the antenna wire. The steel cable had sufficient strength to carry ice formations on the wire as large as 2 inches in diameter. Figure 17 shows the radio antenna successfully carrying a very heavy ice formation. Ice also formed on the antenna anchor insulators, as shown in figure 21. Aluminum shields were placed in front of the antenna lead-in insulators to prevent ice formations from providing an electrical connection between the antenna and the airplane structure. An ice formation on one of the insulator shields is shown in figure 22.

Ice formed on the heated lips of the heat-exchanger air-intake scoops in all of the tests, as shown in figure 23.

Ice accumulations on the unheated surfaces and protuberances of the airplane are shown in figures 20, 21, 22, and 24 to 28.

The only service to the thermal ice-prevention equipment required during the flight-test period was occasional repair of mechanical failures of the heated air dump-valve motor units. Periodic inspections of the heat exchangers failed to reveal deterioration such as corrosive action or fatigue cracks.

DISCUSSION

An inspection of the results of the performance tests on the XB-24F airplane thermal ice-prevention equipment indicates that the installation was adequate, with a few exceptions, to prevent formation of ice on the surfaces for which protection was desired, provided a quantity of heat approaching the design value was supplied to the installation. This conclusion is based upon the fact that at cruising conditions the performance of the wing outer panel and the horizontal stabilizer leading-edge installations was entirely satisfactory, and that the operation of most of the remaining equipment was brought to a satisfactory condition by increasing the power of the engines. The unsatisfactory performance of the wing tips and fin leading-edge outer-skin overlap regions, however, may be attributed to local design and not to an insufficient supply of heat. The fact that flights were safely conducted in all of the icing conditions encountered demonstrates that the operation of the equipment, in general, was adequate and reliable, although the need for further development of some portions of the installation is evident.

A study of the design requirements for the equipment (reference 2) and the performance data tables clearly indicates that further development of the system should start with the consideration of means for increasing the quantities of heat directed to the areas to be protected. Although the wing outer-panel leading edge was maintained free from ice formations with a heat supply of only 50 to 70 percent of the design requirement, supplying the entire design amount would afford a larger margin of protection, would probably eliminate the small ice formations observed on the lower surface aft of leading edge, and would provide an increased source of heat for the wing tips. The amounts of heat supplied to the wing inboard panel and to the empennage were about 75 percent of the design requirement, and for these regions an increase of heat supply is particularly desirable. For example, the intermittent removal of ice formations from the fin leading edge by increasing the engine power during test 12 indicates that the design heat flow might have provided satisfactory protection. For the inboard panel, also, ice formations present under cruising conditions were eliminated by an increase in power.

The primary factor causing the heat supply to the ice-prevention equipment to be below the design requirements was the excessive energy losses experienced by the circulating air throughout the system, with resultant low rates of air flow. The design requirements for each of the four exhaust-gas-to-air heat exchangers were a heat output of 200,000 Btu per hour at an air-flow rate of 2730 pounds per hour, a temperature rise of 300° F, and an air-side pressure drop of 5 inches of water. (See reference 2.) This design pressure drop was approximately one-half of the dynamic pressure of the air stream at the design indicated airspeed (150 mph, q = 11 in. of water). The remaining one-half was to be employed to circulate the heated air through the system aft of the exchanger. Preliminary tests of one of the XB-24F exchangers installed on a single-engine test airplane (fig. 30) showed that when the difference between static pressures before and after the exchanger, in ducts of equal area, was 11 inches of water, the exchanger heat output was 155,000 Btu per hour and the air-flow rate was 2130 pounds per hour. The exchanger air inlet and outlet for these tests were the same as those for the XB-24F installation. These data show that even if all the available dynamic pressure at the design airspeed could be expended in causing air flow through the exchanger, plus inlet and outlet, the heater design performance could not be realized.

Unfortunately, the scope of the test data did not allow a breakdown of the energy losses of the air in passing through the exchanger into those losses attributable to the exchanger alone and those occurring in the air inlet and outlet. In a consideration of the air ducting, however, attention is immediately attracted to the evident restriction to air flow provided by the exchanger air outlet. (See figs. 4 and 30.) The shape of the outlet was largely determined by the space available without relocating or eliminating essential equipment and structural members in the nacelles. The suspicion that the air outlet imposed a restriction on the air flow was confirmed in the first flight tests of the installation, in which excessive air temperatures and very low air-flow rates were noted. An inspection of the exchangers indicated that the region F, A (fig. 4) attained a higher temperature than any other area, as might be expected from a consideration of the outlet, and led to the removal of some of the external pins as outlined in figure 4.

A further comparison of the test data of the exchanger investigations on the single-engine airplane and the performance tests of the entire XB-24F installation indicated that the pressure losses through the system aft of the exchanger were also larger than could be considered desirable, although not to the same degree as the losses through the exchanger. These results show plainly the necessity for careful consideration of the design of the circulating-air path. An attempt should be made to design the heat exchanger in such a manner that energy losses which do not contribute to the transfer of heat are minimized. Consideration should be given in designing the exchanger to the manner in which the circulating air is to be directed to and from the heating surfaces, in order to reduce the energy losses in the inlet and outlet. The use of guide vanes in the air inlet is undesirable unless provision is made to prevent ice formations from restricting the air flow. The inner surfaces of all ducts should be smooth, curves should be gradual and of formed construction, turns in rectangular ducts should be about an axis parallel to the longer dimension, and consideration should be given to the use of guide vanes.

The equipment was tested in natural icing conditions without making the necessary revisions to increase the performance, for the following reasons:

1. A redesign of the exchanger air outlet would involve considerable alterations to the interior of the nacelles, and probable inclusion of the air intake in the nacelle structure to provide ice protection and increased aerodynamic cleanness.

2. A study of the performance of the equipment in the dry-air flights indicated that the heating of the wing outer panels appeared adequate, and the heating of the empennage was marginal. Further alterations to improve the performance would have delayed the program a full year, and since former flight-test experience

under natural icing conditions suggested that the operation of the equipment, in general, would be satisfactory, the tests were conducted without further changes.

The performance of the wing tip and the central portions of the leading edge of the fins emphasizes the necessity of obtaining proper internal distribution of the heated air, and of circulating this air in direct contact with the inner surface of the outer skin. In the case of the wing tip, the design would be improved by employing an inner, secondary skin rather than the outer cap, thus continuing the outer-panel leading-edge design to the extreme tip. Although the outer-skin installation on the horizontal stabilizer provided satisfactory performance, the empennage installation would be improved by providing the inner-skin type of construction for the stabilizer and fin leading edges. The external-skin type of construction was used on the leading edges of the XB-24F empennage because the alterations to the airplane structure were simple and because of the suction imposed on the heated-air supply system by locating the air-exit gap in a low-pressure region. For any new installation in which redesign of the entire leading edge is being considered, however, the small loss in circulating air potential incurred by employing an internal, rather than external, secondary skin would be offset by the increased ice-removal efficiency of the system aft of the leading edge, resulting from internal circulation of the heated air. Furthermore, an internal-skin system would result in greater aerodynamic cleanness of the installation.

An exact determination of the effect of the icing conditions on the heat transfer from the leading-edge surfaces, by a comparison of the surface temperature rises obtained during the dry-air and icing tests, is not possible because of the variations in the test conditions. In general, however, the approximate average values of leading-edge skin temperature rises (100° F, dry air, and 90° F, icing) and heat flows (725 Btu per hr per sq ft, dry air; 850, icing) indicate that the heat transfer from the outer surface was increased by approximately 20 to 30 percent in the icing flights.

The performance of the heated windshield revealed the necessity for employing a glass outer panel in the heated-air double-pane type of design, or a material of equivalent thermal conductivity. For the inner panel, the use of a plastic which will maintain its form at a temperature of 200° F is recommended.

The strength of the internal structure of the XB-24F airplane was unaffected by the elevated temperatures resulting from the thermal ice-prevention equipment installation. The highest recorded structure temperature was 206° F, obtained in an unreported flight, and the thermal equipment was employed during take-off in the icing investigations without visible damage to the wing structure or equipment.

The need for further extension of the ice-prevention equipment is evident from a consideration of figures 24, 25, and 27. In the case of the leading edges of the engine cowls (fig. 24) continuous flight in icing conditions resulted in an area reduction of the carburetor, oil cooler, and intercooler air intakes of approximately 50 percent. Obviously stoppage of these openings would terminate the flight irrespective of the satisfactory operation of other parts of the ice-prevention equipment. The protection of the air inlet to the heat exchanger should also be given considerable attention in the design.

Because of the importance attached to the operation of the valves which discharge the heated air or direct it to the ice-prevention equipment, control of these valves should be obtained by a simple, mechanical system. If an electrical or hydraulic control system is employed, a mechanical, secondary installation should be provided for emergency use. An indicator should also be provided to show that operation of the valve control or controls has produced the desired valve action.

CONCLUSIONS

1. The performance tests of the thermal ice-prevention equipment in the XB-24F airplane under natural icing conditions demonstrated that the performance specification adopted for the design of the installation was satisfactory and should prove entirely adequate for any similar future installation.

2. Sufficient data are available to prepare a thermal ice-prevention equipment design which will meet the performance specification employed for the XB-24F installation and which will be structurally satisfactory from a stress and a production standpoint.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif., Oct. 7, 1943.

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TABLE I

DATA RECORDED DURING TESTS OF THERMAL ICE-PREVENTION EQUIPMENT ON THE XB-24F AIRPLANE IN NON-ICING CONDITIONS (MOFFETT FIELD, CALIF.)

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Test number - - - - - - -	1	2	3	4	5
Condition - - - - - - - - -	Level Flight	Level Flight	Level Flight	Level Flight	Ground Run
Date - - - - - - - - - - -	10/12/42	10/15/42	10/16/42	10/16/42	10/16/42
Time - - - - - - - - - - -	2:25P.M. to 4:10P.M.	10:50A.M. to 12:15P.M.	10:40A.M. to 12:00Noon	12:00Noon to 1:20P.M.	3:00P.M. to 3:30P.M.
Pressure altitude, feet -	10,000	10,000	18,000	18,000	0
Free air temperature, °F -	40	50	23	23	81
Correct indicated air-speed, mph - - - - - -	150	150	150	150	0
Manifold pressure, No. 1 engine, in. of Hg - - -	25	27	30	32	0
Manifold pressure, No. 2 engine, in. of Hg - - -	25	21	30	17.5	0
Manifold pressure, No. 3 engine, in. of Hg - - -	25	25	30	18	0
Manifold pressure, No. 4 engine, in. of Hg - - -	25	25	24	35	17
Rpm, No. 1 engine - - - -	2,000	2,000	2,000	2,400	0
Rpm, No. 2 engine - - - -	2,000	2,000	2,000	2,200	0
Rpm, No. 3 engine - - - -	2,000	2,000	2,000	2,200	0
Rpm, No. 4 engine - - - -	2,000	2,000	2,000	2,400	1,500

TABLE II

RESULTS OF TESTS OF THERMAL ICE-PREVENTION EQUIPMENT IN RIGHT WING OUTER PANEL, XB-24F AIRPLANE IN NON-ICING CONDITIONS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Thermo-couple Number	Test number	1	3	5
	Pressure altitude, ft	10,000	18,000	0
	Correct IAS, mph	150	150	0
	Free air temperature, °F	40	23	81
	Weight of air to outboard section, lb/hr	1,410	1,220	--
A17	Temperature of air out of exchanger, °F	347	358	358
	Temperature rise, °F	307	335	277
	Heat to air, Btu/hr	103,000	98,000	--
	Air temperatures, °F			
A18	At 5-inch venturi	329	335	331
A14	In duct outlet No. 1, sta. 368	306	311	309
A10	In duct outlet No. 2, sta. 450	282	288	285
A7	In duct outlet No. 3, sta. 515	264	267	262
A4	In duct outlet No. 4, sta. 588	256	253	240
A15	Forward of baffle, sta. 351	245	243	240
A16	Behind baffle, sta. 349	103	96	149
A11	Forward of baffle, sta. 390	257	254	246
A12	Behind baffle, sta. 387	148	138	160
A8	Forward of baffle, sta. 495	194	188	211
A9	Behind baffle, sta. 493	125	113	160
A5	Forward of baffle, sta. 549	225	224	223
A6	Behind baffle, sta. 547	137	125	165
A2	Forward of baffle, sta. 609	220	213	210
A3	Behind baffle, sta. 608	144	133	162
A42	Inside wing tip, near leading edge	91	76	112
A13	Inside wing at rear spar, sta. 390	53	35	93
A1	In wing, mid-chord, sta. 620	102	83	134

TABLE II (CONCLUDED)

NATIONAL ADVISORY
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Thermo-couple number	Test number - - - - - - - - - - - - - - - -	1	3	5
	Skin temperatures, °F above free air temperature			
S15	Lower surface at front spar, sta. 382 - -	79	83	42
S14	Lower surface at baffle, sta. 380 - - - -	128	132	80
S13	On nose, sta. 380 - - - - - - - - - - - - -	120	126	82
S11	Upper surface, at baffle, sta. 380- - - -	135	141	84
S12	Upper surface, at front spar, sta. 382- -	46	10	42
S17	Lower surface, mid-chord, sta. 390- - - -	⁻3	9	6
S16	Upper surface, mid-chord, sta. 390- - - -	6	17	11
S18	Upper surface, sta. 390 - - - - - - - - - -	6	17	5
S10	Lower surface, at front spar, sta. 476- -	76	81	72
S9	On nose, sta. 483 - - - - - - - - - - - - -	104	104	105
S8	Upper surface, at front spar, sta. 476- -	54	57	80
S7	Lower surface, mid-chord, sta. 595- - - -	13	18	19
S6	Upper surface, mid-chord, sta. 595- - - -	13	18	39
S5	Lower surface, at front spar, sta. 604- -	97	101	79
S4	On nose, sta. 605 - - - - - - - - - - - - -	110	113	106
S3	Upper surface, at front spar, sta. 604- -	58	70	81
S1	Upper surface, mid-chord, sta. 604- - - -	10	17	34
S2	Aileron seal skin, sta. 604 - - - - - - - -	17	21	17
S45	Lower surface, wing tip, 4 inches from leading edge - - - - - - - - - - - - - - -	37	41	24
S43	On nose, wing tip, sta. 630 - - - - - - - -	25	27	31
S44	Upper surface, wing tip, 4 inches from leading edge - - - - - - - - - - - - - - -	36	41	39
	Structure temperatures, °F			
M1	On nose-rib web near front spar, sta.387-	102	92	130
M2	On nose-rib web near baffle, sta. 387 - -	168	156	167
Pressure Orifice Number	Pressures in inches of water referred to free-stream static pressure (+above, - below)			
P1	On baffle near No. 4 outlet, sta. 586 - -	+0.6	-0.8	--
P3	On rib aft of baffle, sta. 545- - - - - -	+0.4	-1.1	--
P4	At trailing edge near exit, sta. 565- - -	+0.2	-1.5	--
P5	On baffle near No. 3 outlet, sta. 515 - -	+0.9	-0.8	--
P6	On baffle near No. 2 outlet - - - - - - -	+1.1	-0.8	--
P8	On rib aft of baffle, sta. 387- - - - - -	+1.1	-1.2	--
P9	At trailing edge, near exit, sta. 392 - -	+0.8	-1.5	--
P10	On baffle near No. 1 outlet, sta. 363 - -	+0.8	-1.3	--

TABLE III

RESULTS OF TESTS OF THERMAL ICE-PREVENTION EQUIPMENT IN RIGHT WING INBOARD PANEL, XB-24F AIRPLANE IN NON-ICING CONDITIONS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Thermocouple Number	Test number	2	4
	Pressure altitude, ft	10,000	18,000
	Correct IAS, mph	150	150
	Free air temperature, °F	50	23
	Weight of air to inboard section, lb/hr (each side)	570	462
	Weight of air to empennage, lb/hr	2,160	1,860
	Weight of air per exchanger, lb/hr	1,650	1,392
	Average temperature of air into exchanger, °F	50	26
A25	Temperature of air out of exchanger, °F	376	341
	Temperature rise	326	315
	Heat to air, Btu/hr (each exchanger)	129,000	105,500
	Air temperatures, °F		
A23	Entering distribution duct	300	278
A21	In distribution duct, sta. 193	310	285
A22	Out of corrugations, sta. 193	101	80
A19	In distribution duct, sta. 250	233	209
A20	Out of corrugations, sta. 250	98	80
	Skin temperatures, °F above free air temperature		
S27	Lower at front spar, sta. 193	125	136
S26	On nose, sta. 193	102	102
S25	Upper at front spar, sta. 193	55	53
S22	Lower at front spar, sta. 250	106	105
S21	On nose, sta. 250	76	80
S20	Upper at front spar, sta. 250	43	45
S23	Upper, 30-percent chord, sta. 250	8	12
S24	Upper, 60-percent chord, sta. 250	5	12
Pressure Orifice Number	Pressures in inches of water referred to free stream static pressure (above, - below)		
P11	Static at exchanger entrance, upper, No. 3 nacelle	+9.3	+9.1
P14	Total at exchanger entrance, upper, No. 3 nacelle	+12.0	+12.0
P40	Total at exchanger entrance, lower, No. 3 nacelle	+13.4	+13.4
P41	Static at exchanger entrance, lower, No. 3 nacelle	+10.4	+10.6
P19	Near duct entrance, sta. 179	--	0
P18	In delivery duct, sta. 250	--	+0.2
P17	In corrugation, sta. 250	--	-8.8

TABLE IV

RESULTS OF TESTS OF THERMAL ICE-PREVENTION EQUIPMENT FOR THE EMPENNAGE OF THE XB-24F AIRPLANE IN NON-ICING CONDITIONS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Thermo-couple Number	Test number	2	4
	Pressure altitude, ft	10,000	18,000
	Correct IAS, mph	150	150
	Free air temperature, °F	50	23
	Weight of air to empennage, lb/hr	2,160	1,860
	Stabilizer air temperature, °F		
A46	At 6-inch venturi	323	306
A33	In duct, joggled region	313	295
A30	Inside leading edge, near fuselage	137	117
A32	Out of lower gap, inboard	61	42
A31	Out of upper gap, inboard	70	49
A29	In leading edge interior, near fin	197	176
A28	Out of lower gap, outboard	92	74
A27	Out of upper gap, outboard	138	120
A26	In plenum chamber	267	250
	Stabilizer skin temperatures, °F above free air temperature		
S35	Lower at front spar, inboard	10	19
S33	On nose, inboard	46	62
S34	Upper at front spar, inboard	13	23
S32	Lower at front spar, semi-span	0	10
S31	Upper at front spar, semi-span	11	16
S36	Lower at rear spar, semi-span	1	8
S30	Lower at front spar, outboard	30	36
S28	On nose, outboard	104	108
S29	Upper at front spar, outboard	123	127
	Fin air temperatures, °F		
A37	In duct, upper outlet	247	228
A36	Out of upper outboard gap	98	75
A35	Out of upper inboard gap	110	81
A38	In duct, lower outlet	245	226
A40	Out of lower outboard gap	87	68
A39	Out of lower inboard gap	93	71

TABLE IV (CONCLUDED)

NATIONAL ADVISORY
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Thermo-couple Number	Test number - - - - - - - - - - - - - - - - - -	2	4
	Fin skin temperatures, °F above free air temperature		
S39	Top, outboard, at gap - - - - - - - - - - - - -	45	57
S37	Top, on nose - - - - - - - - - - - - - - - - -	53	62
S38	Top, inboard, at gap - - - - - - - - - - - - -	56	62
S42	Bottom, outboard, at gap - - - - - - - - - - -	35	42
S40	Bottom, on nose - - - - - - - - - - - - - - - -	42	53
S41	Bottom, inboard, at gap - - - - - - - - - - - -	22	32
	Pressures in inches of water referred to free-stream static pressure (+above, - below)		
P29	Air duct, stabilizer root - - - - - - - - - - -	-1.3	-0.8
P27	Upper air gap, stabilizer root - - - - - - - -	-7.0	-6.3
P28	Lower air gap, stabilizer root - - - - - - - -	-5.2	-4.6
P25	Upper air gap, stabilizer tip - - - - - - - - -	-9.8	-8.8
P26	Lower air gap, stabilizer tip - - - - - - - - -	-9.3	-7.3
P24	Stabilizer tip plenum chamber - - - - - - - - -	-0.6	-0.8
P32	Air outlet inside fin, top- - - - - - - - - - -	-0.4	-1.8
P33	Air outlet inside fin, bottom - - - - - - - - -	-0.4	-1.8
P30	Air gap, top of fin, inboard - - - - - - - - -	-3.8	-3.8
P31	Air gap, top of fin, outboard - - - - - - - - -	-1.8	-2.5
P34	Air gap, bottom of fin, inboard - - - - - - - -	-2.0	-2.8
P35	Air gap, bottom of fin, outboard - - - - - - -	-2.6	-3.0

TABLE V

DATA RECORDED DURING FLIGHT TESTS OF THERMAL ICE-PREVENTION EQUIPMENT ON THE XB-24F AIRPLANE IN ICING CONDITIONS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Test number	6	7	8	9	10	11	12	[a]13	[a]14	[a]15	[a]16
Condition	level flight	level flight	level flight	level flight	level flight	level flight	level flight	level flight	level flight	level flight	level flight
Date	1/14/43	1/24/43	1/24/43	2/3/43	2/5/43	2/5/43	2/9/43	12/30/42	2/12/43	1/1/43	1/9/43
Time of test	10:50a.m. to 12:30p.m.	12 noon to 12:40p.m.	1:00p.m. to 1:15p.m.	3:45p.m. to 4:15p.m.	4:15p.m. to 4:30p.m.	4:40p.m. to 5:00p.m.	4:00p.m. to 4:25p.m.	11:20a.m. to 12 noon	1:15p.m. to 2:00p.m.	10:45a.m. to 2:45p.m.	9:20a.m. to 11:00a.m.
Location	Eau Claire, Wisc.	Wausau, Wisc.	Eau Claire, Wisc.	Alexandria, Minn.	Cass Lake, Minn.	Little Falls, Minn.	Onamia, Minn.	Sandstone, Minn.	Park Rapids, Minn.	Minneapolis, Minn.	Lone Rock, Wisc.
Icing condition	rime, light to moderate	rime, light to moderate	rime, light to moderate	glaze, moderate	rime, light	rime, light	rime, light to moderate	rime, light	rime, light	rime and glaze, light	rime, light to moderate
Pressure altitude, ft	6200	2800-3300	4000	3900-4000	5300-6000	4500-4700	4200-4300	3500-5000	5800-6600	2200-4100	3000-5000
Free-air temperature, °F	15	20 to 22	23	27	16 to 27	18 to 20	25	18 to 30	4 to-3	15 to 26	18 to 26
Correct indicated airspeed, mph	150	171-181	186	165-177	161-171	176-191	161-181	175-182	156-186	162-175	173-184
Manifold pressure, No. 1 engine, in. of Hg	29	30	30	31	31	31	30	30.5	30	29	30
Manifold pressure, No. 2 engine, in. of Hg	28	30	30	31	31	31	30	30.5	30	29	30
Manifold pressure, No. 3 engine, in. of Hg	28	30	30	31	31	31	30	30.5	30	29	30
Manifold pressure, No. 4 engine, in. of Hg	29	30	30	31	31	31	30	30.5	30	29	30
Rpm, No. 1 engine	2050	2050	2050	2050	2050	2050	2050	2000	2050	2050	2050
Rpm, No. 2 engine	2050	2050	2050	2050	2050	2050	2050	2000	2050	2050	2050
Rpm, No. 3 engine	2050	2050	2050	2050	2050	2050	2050	2000	2050	2050	2050
Rpm, No. 4 engine	2050	2050	2050	2050	2050	2050	2050	2000	2050	2050	2050

[a]No thermal data obtained during these tests.

TABLE VI

RESULTS OF FLIGHT TESTS OF THERMAL ICE-PREVENTION EQUIPMENT IN RIGHT WING OUTER PANEL, XB-24F AIRPLANE IN ICING CONDITIONS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Thermo-couple number	Test number	6	7	8	9	10	11
	Pressure altitude, ft	6200	3100	4000	6000	4500	4300
	Correct IAS, mph	150	171	171	161-171	186-191	181
	Free air temperature, °F	15	22	27	16	20	25
	Weight of air to outboard section, lb/hr	1300	1700	1800	--	--	1735
A17	Temperature of air out of exchanger, °F	346	315	347	346	309	340
	Temperature rise, °F	331	293	320	330	289	315
	Heat to air, Btu/hr	103,000	119,500	138,000	--	--	131,000
	Air temperatures, °F						
A18	At 5-inch venturi	331	305	334	333	300	326
A14	In duct outlet No. 1, sta. 368	--	272	310	--	280	304
A10	In duct outlet No. 2, sta. 450	--	251	289	--	271	286
A7	In duct outlet No. 3, sta. 515	--	236	266	--	250	265
A4	In duct outlet No. 4, sta. 588	--	245	260	--	243	253
A15	Forward of baffle, sta. 351	235	231	260	262	240	251
A16	Behind baffle, sta. 349	96	105	117	109	110	111
A11	Forward of baffle, sta. 390	--	235	266	--	252	262
A12	Behind baffle, sta. 387	--	152	169	--	156	158
A8	Forward of baffle, sta. 495	174	180	199	199	194	190
A9	Behind baffle, sta. 493	102	112	126	124	124	113
A5	Forward of baffle, sta. 549	209	222	235	230	219	225
A6	Behind baffle, sta. 547	112	125	139	130	134	122
A2	Forward of baffle, sta. 609	205	225	230	221	215	222
A3	Behind baffle, sta. 608	116	146	145	130	134	128
A42	Inside wing tip, near leading edge	--	80	84	--	80	79
A13	Inside wing at rear spar, sta. 390	--	45	45	--	26	42
A1	In wing, mid-chord, sta. 620	--	96	96	--	80	84
	Skin temperatures, °F above free air temperature						
S15	Lower surface at front spar, sta. 382	--	63	84	--	84	60
S14	Lower surface at baffle, sta. 380	107	103	138	149	138	115
S13	On nose, sta. 380	119	88	128	143	130	95
S11	Upper surface, at baffle, sta. 380	130	123	139	153	139	125
S12	Upper surface at front spar, sta. 382	--	52	60	--	74	50
S17	Lower surface, mid-chord, sta. 390	--	13	16	--	12	13
S16	Upper surface, mid-chord, sta. 390	--	15	18	--	12	13
S18	Upper surface, sta. 390	--	14	14	--	3	10
S10	Lower surface at front spar, sta. 476	65	63	73	93	79	54
S9	On nose, sta. 483	85	83	110	123	107	76
S8	Upper surface at front spar, sta. 476	58	59	67	75	69	54
S7	Lower surface, mid-chord, sta. 595	--	23	21	--	16	16
S6	Upper surface, mid-chord, sta. 595	--	19	21	--	16	16
S5	Lower surface at front spar, sta. 604	120	78	92	113	94	59
S4	On nose, sta. 605	90	88	110	129	99	83
S3	Upper surface at front spar, sta. 604	53	57	58	70	64	54
S1	Upper surface, mid-chord, sta. 604	--	18	18	--	15	16
S2	Aileron seal skin, sta. 604	--	27	27	--	15	24
S45	Lower surface, wing tip, 4 inches from leading edge	--	--	40	--	28	33
S43	On nose, wing tip, sta. 630	30	29	37	44	28	41
S44	Upper surface, wing tip, 4 inches from leading edge	--	23	37	--	28	30
	Structure temperatures, °F						
M1	On nose-rib web near front spar, sta. 387	--	91	105	--	--	98
M2	On nose-rib web near baffle, sta. 387	--	155	176	--	--	167

TABLE VII

RESULTS OF FLIGHT TESTS OF THERMAL ICE-PREVENTION EQUIPMENT IN RIGHT WING INBOARD PANEL, XB-24F AIRPLANE IN ICING CONDITIONS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Thermocouple number	Test number	6	7	8	9	10	11	12
	Pressure altitude, ft	6200	3300	4000	4000	5300	4700	4200
	Correct IAS, mph	150	171	186	165	161	176-186	181
	Free air temperature, °F	15	22	23	27	16	18	26
	Weight of air to inboard section, lb/hr (each side)	620	655	738	606	922	--	576
	Weight of air to empennage, lb/hr	2160	2670	2810	1830	2330	--	2140
	Weight of air per exchanger, lb/hr	1700	1990	2143	1521	2087	--	1646
	Average temperature of air into exchanger, °F	15	30	23	32	18	20	31
A25	Temperature of air out of exchanger, °F	343	294	276	302	269	274	289
	Temperature rise	328	264	253	270	251	254	258
	Heat to air, Btu/hr (each exchanger)	140,000	126,000	130,000	98,500	126,000	--	102,000
	Air temperatures, °F							
A23	Entering distribution duct	--	236	--	248	--	215	230
A21	In distribution duct, sta. 193	261	244	245	242	215	215	226
A22	Out of corrugations, sta. 193	78	75	65	72	61	66	68
A19	In distribution duct, sta. 250	180	176	175	153	140	140	148
A20	Out of corrugations, sta. 250	74	75	65	69	59	60	68
	Skin temperatures, °F above free air temperature							
S27	Lower at front spar, sta. 193	123	122	100	83	122	106	85
S26	On nose, sta. 193	17	13	9	18	22	15	12
S25	Upper at front spar, sta. 193	57	58	42	42	55	51	37
S22	Lower at front spar, sta. 250	98	92	81	69	94	81	64
S21	On nose, sta. 250	70	65	56	52	65	61	53
S20	Upper at front spar, sta. 250	41	41	34	32	39	37	25
S23	Upper, 30-percent chord, sta. 250	--	23	--	18	--	7	13

TABLE VIII

RESULTS OF FLIGHT TESTS OF THERMAL ICE-PREVENTION EQUIPMENT FOR THE EMPENNAGE OF THE XB-24F AIRPLANE IN ICING CONDITIONS

Thermo-couple number	Test number	6	7	9	11	12
	Pressure altitude, ft	6200	2800	3900	4500	4200
	Correct IAS, mph	150	181	177	181	161
	Free air temperature, °F	15	20	27	19	25
	Weight of air to empennage, lb/hr	2160	2670	1830	--	2140
	Stabilizer air temperatures, °F					
A46	At 6-inch venturi	--	285	290	265	278
A33	In duct, joggled region	315	280	251	245	264
A30	Inside leading edge, near fuselage	--	110	84	--	93
A32	Out of lower gap, inboard	--	38	43	--	48
A31	Out of upper gap, inboard	--	43	43	--	49
A29	In leading edge interior, near fin	--	171	126	--	139
A28	Out of lower gap, outboard	--	94	70	--	61
A27	Out of upper gap, outboard	--	115	100	--	93
A26	In plenum chamber	264	239	176	176	186
	Stabilizer skin temperatures, °F above free air temperature					
S35	Lower at front spar, inboard	--	20	16	15	16
S33	On nose, inboard	--	54	39	36	33
S34	Upper at front spar, inboard	--	20	16	16	16
S32	Lower at front spar, semi-span	--	11	13	6	13
S31	Upper at front spar, semi-span	--	15	14	15	13
S36	Lower at rear spar, semi-span	--	10	9	9	13
S30	Lower at front spar, outboard	--	29	27	22	25
S28	On nose, outboard	60	95	64	61	33
S29	Upper at front spar, outboard	--	65	92	77	75
	Fin air temperatures, °F					
A37	In duct, upper outlet	--	220	183	--	181
A36	Out of upper outboard gap	--	78	95	--	78
A35	Out of upper inboard gap	--	104	86	--	68
A38	In duct, lower outlet	--	220	177	--	180
A40	Out of lower outboard gap	--	61	64	--	48
A39	Out of lower inboard gap	--	48	53	--	39
	Fin skin temperatures, °F above free air temperature					
S39	Top, outboard, at gap	--	50	39	40	36
S37	Top, on nose	58	71	49	46	33
S38	Top, inboard, at gap	--	45	39	41	40
S42	Bottom, outboard, at gap	--	36	36	32	30
S40	Bottom, on nose	58	65	48	44	30
S41	Bottom, inboard, at gap	--	25	27	27	16

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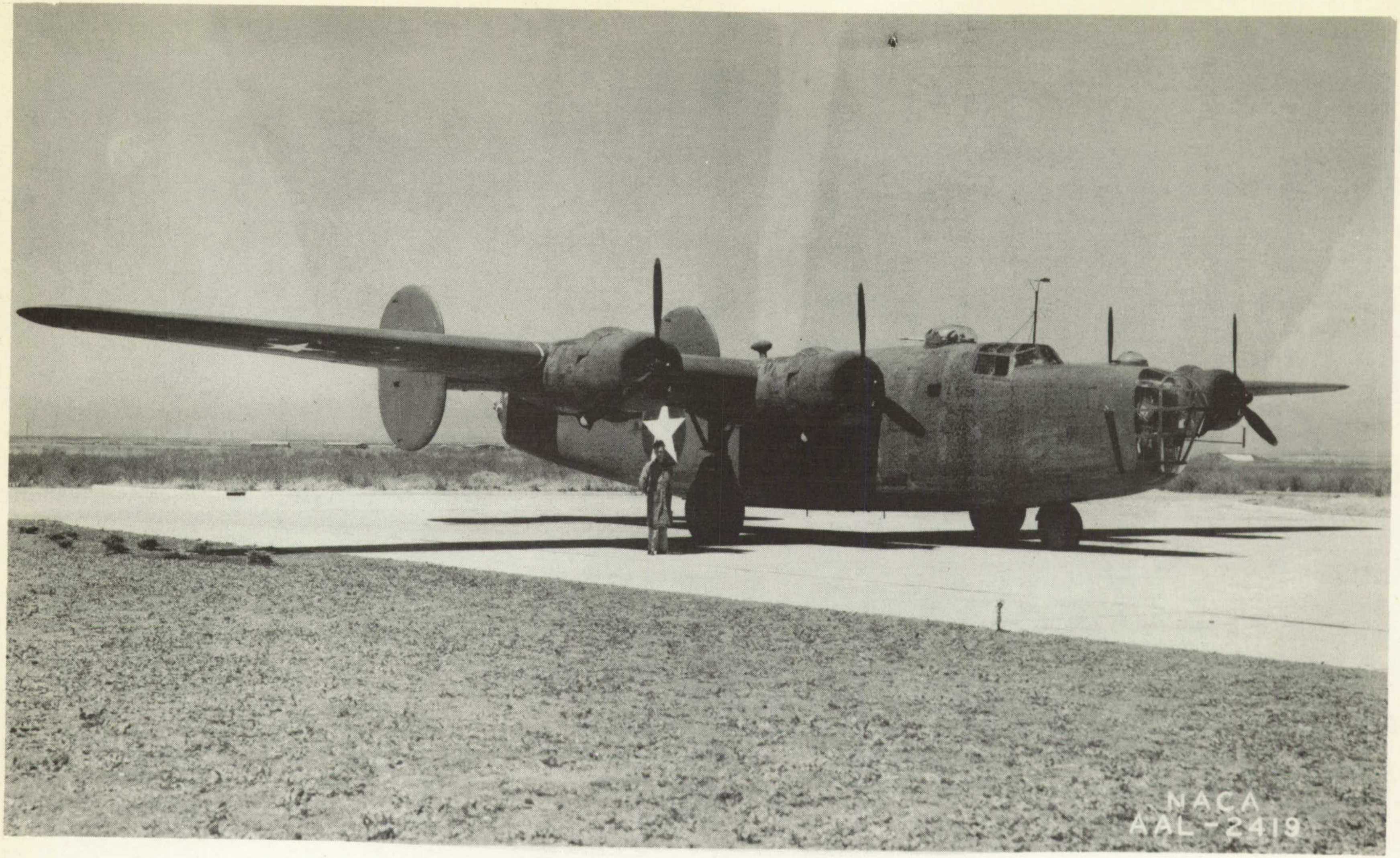


Figure 1.- The XB-24F airplane in which the flight tests of the thermal ice-prevention equipment were made.

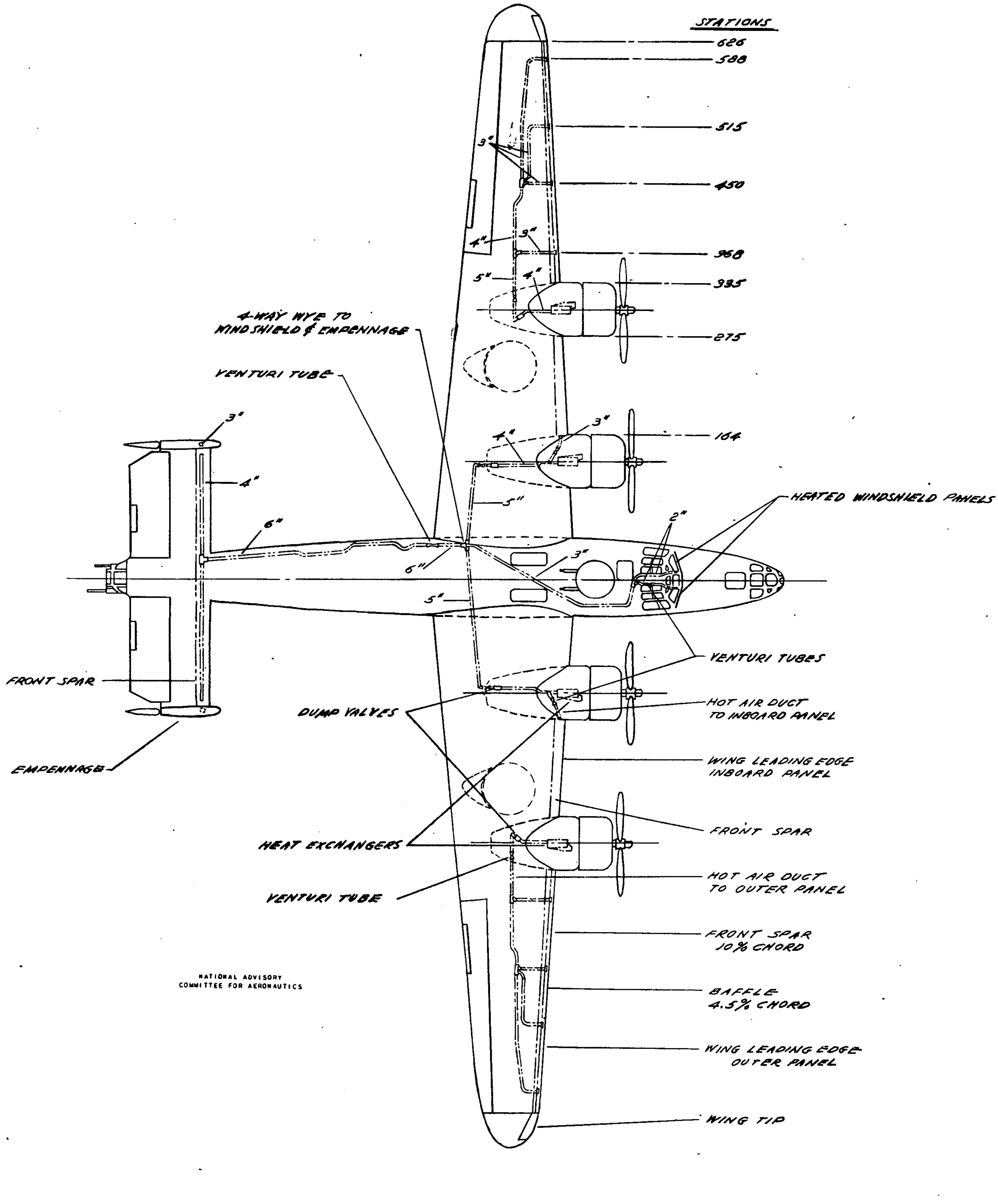


FIGURE 2-THE INSTALLATION OF THE THERMAL ICE PREVENTION EQUIPMENT IN THE XB-24F AIRPLANE. (FIGURE 2, REFERENCE 1)

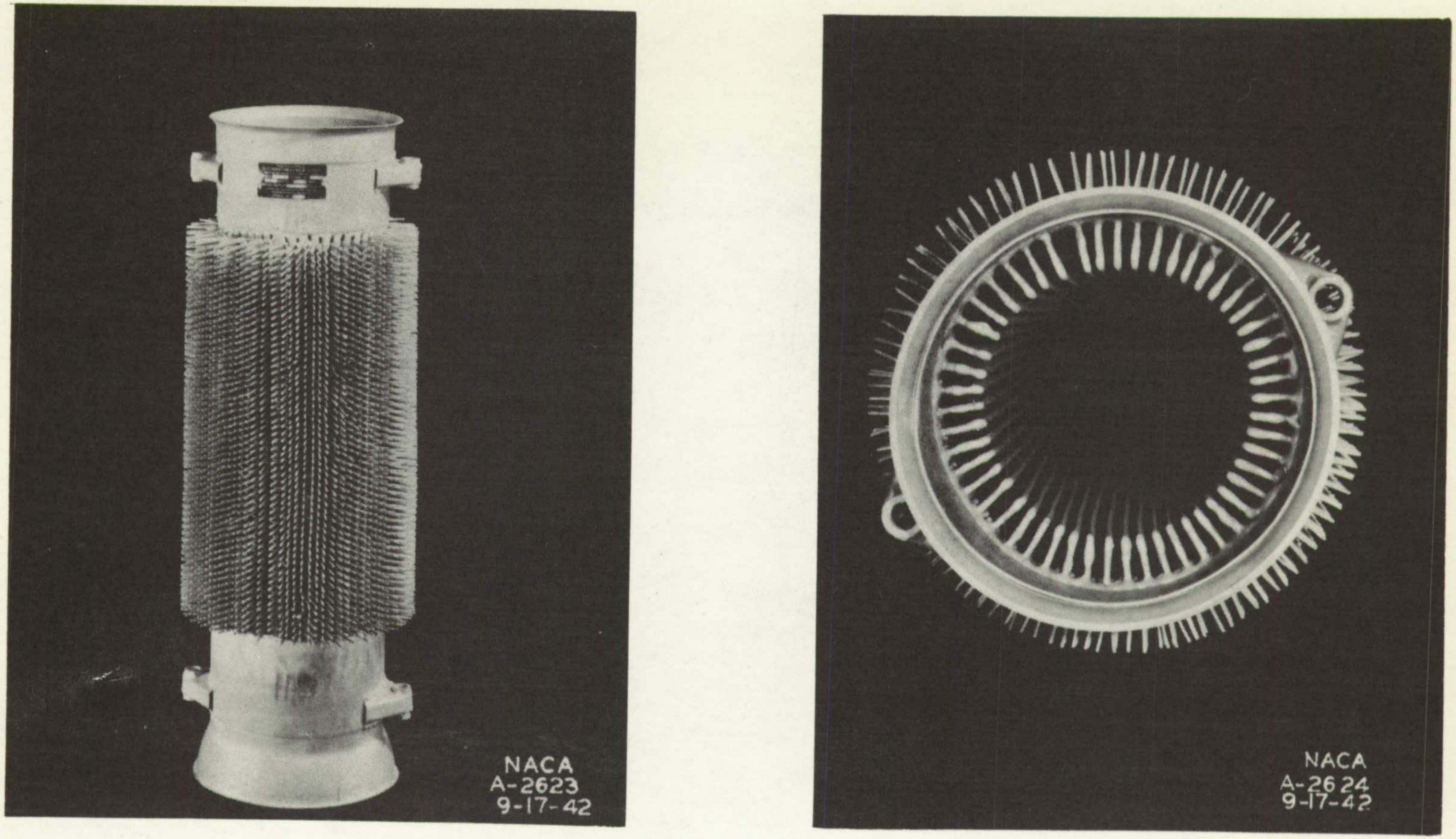
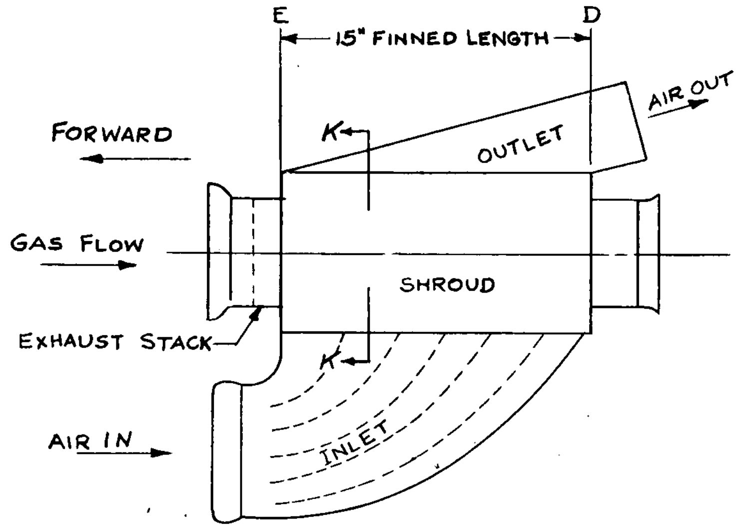


Figure 3. - Pin-fin-type exhaust-gas-to-air heat exchanger used for tests on the XB-24F airplane.



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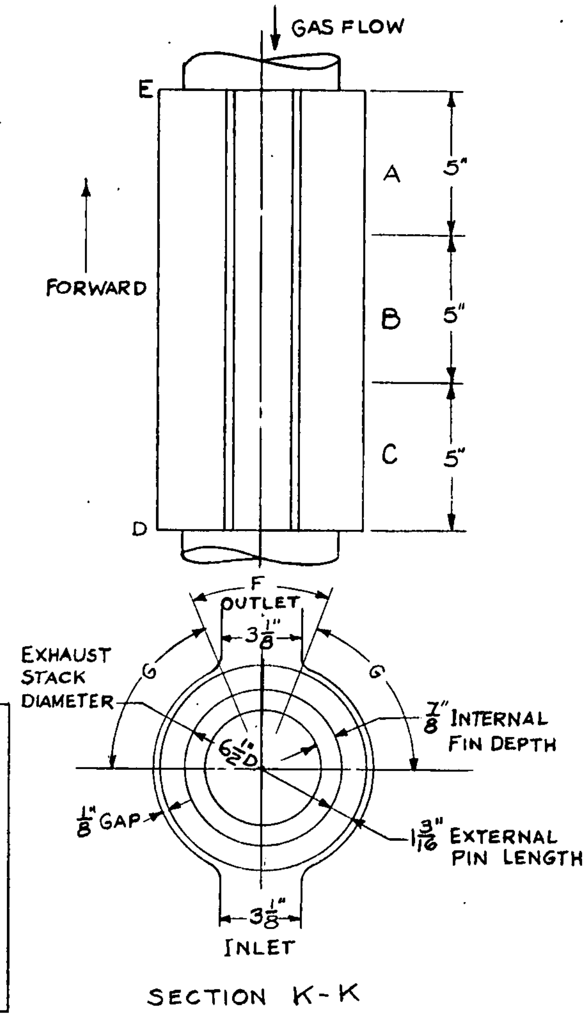

REVISIONS TO EXCHANGERS #1 & #4	REVISIONS TO EXCHANGERS #2 & #3
REGION F ALL PINS REMOVED FOR FULL LENGTH REGION G, SECTION A EVERY OTHER PIN REMOVED REGION G, SECTION B EVERY THIRD PIN REMOVED	REGION F PINS TAPERED FROM 1/4" AT E TO FULL HEIGHT AT D REGION G, SECTIONS A AND B SAME AS FOR #1 & #4

FIGURE 4.- REVISIONS TO PIN-FIN HEAT EXCHANGERS FOR TESTS OF THE XB-24F THERMAL ICE-PREVENTION EQUIPMENT.

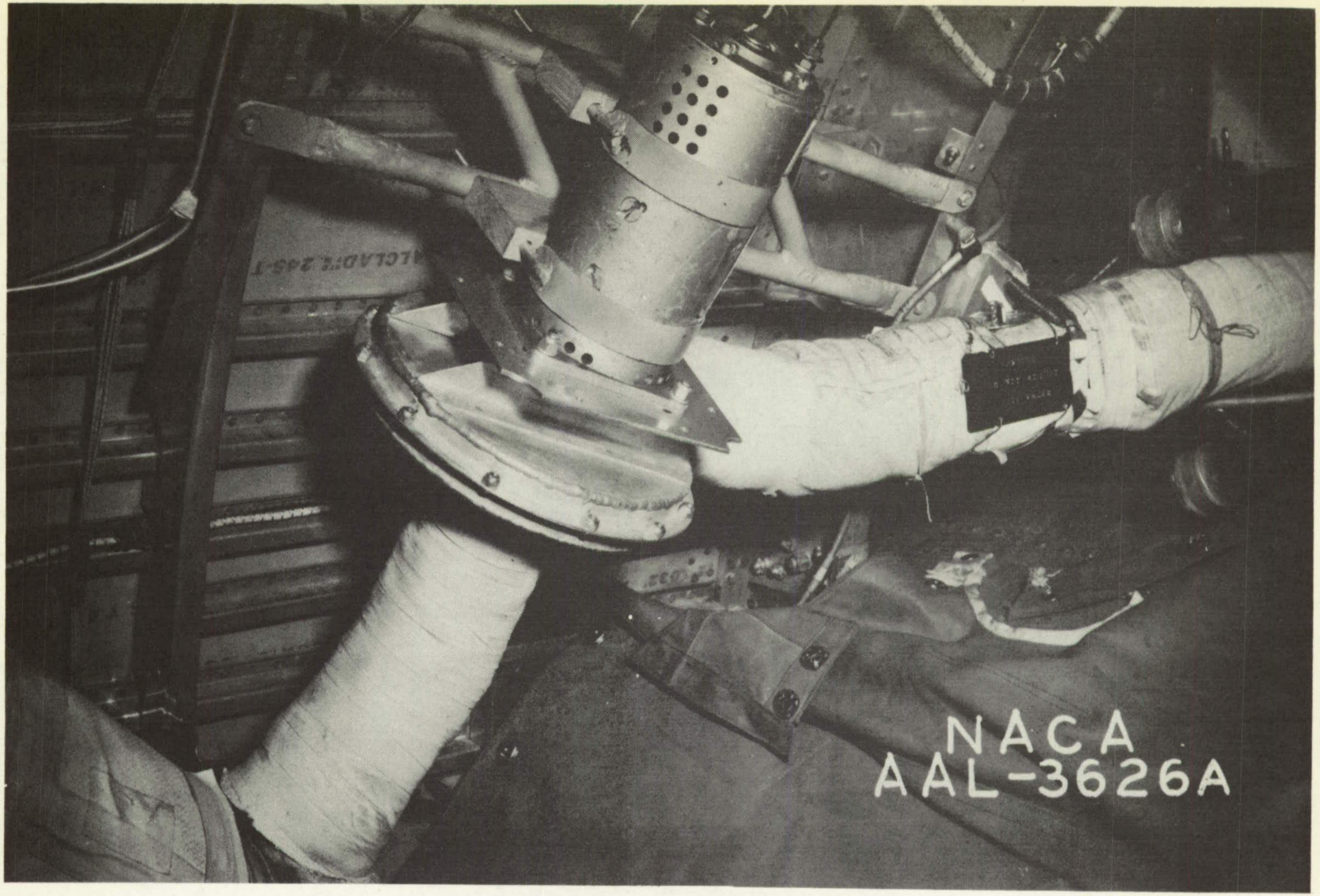

Figure 5.- Blower installed in 3-inch duct to the pilots' windshields to increase the heated-air flow.

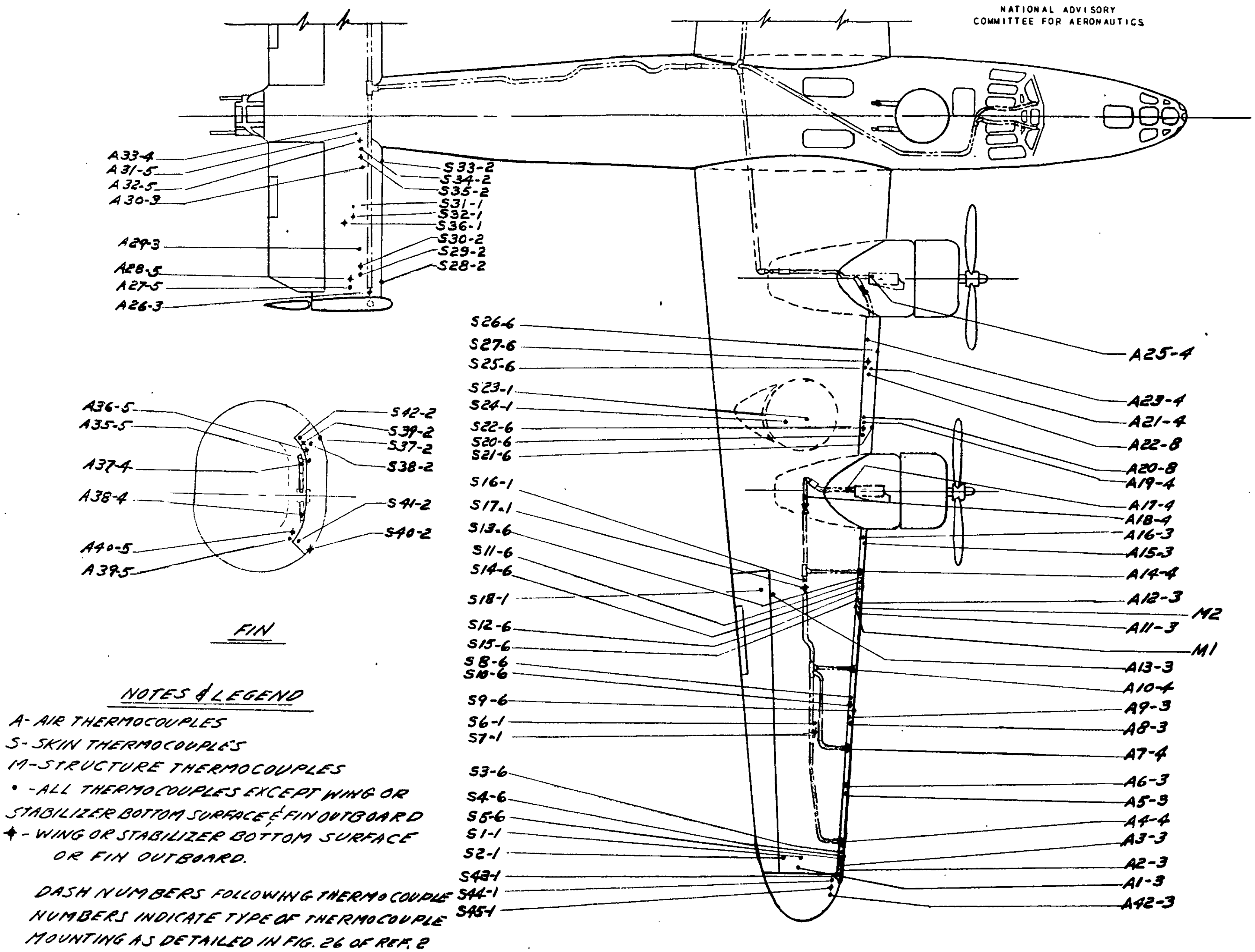

FIGURE 6.- THERMOCOUPLE LOCATIONS ON THE XB-24F AIRPLANE EMPLOYED IN TESTS OF THE THERMAL ICE-PREVENTION EQUIPMENT.

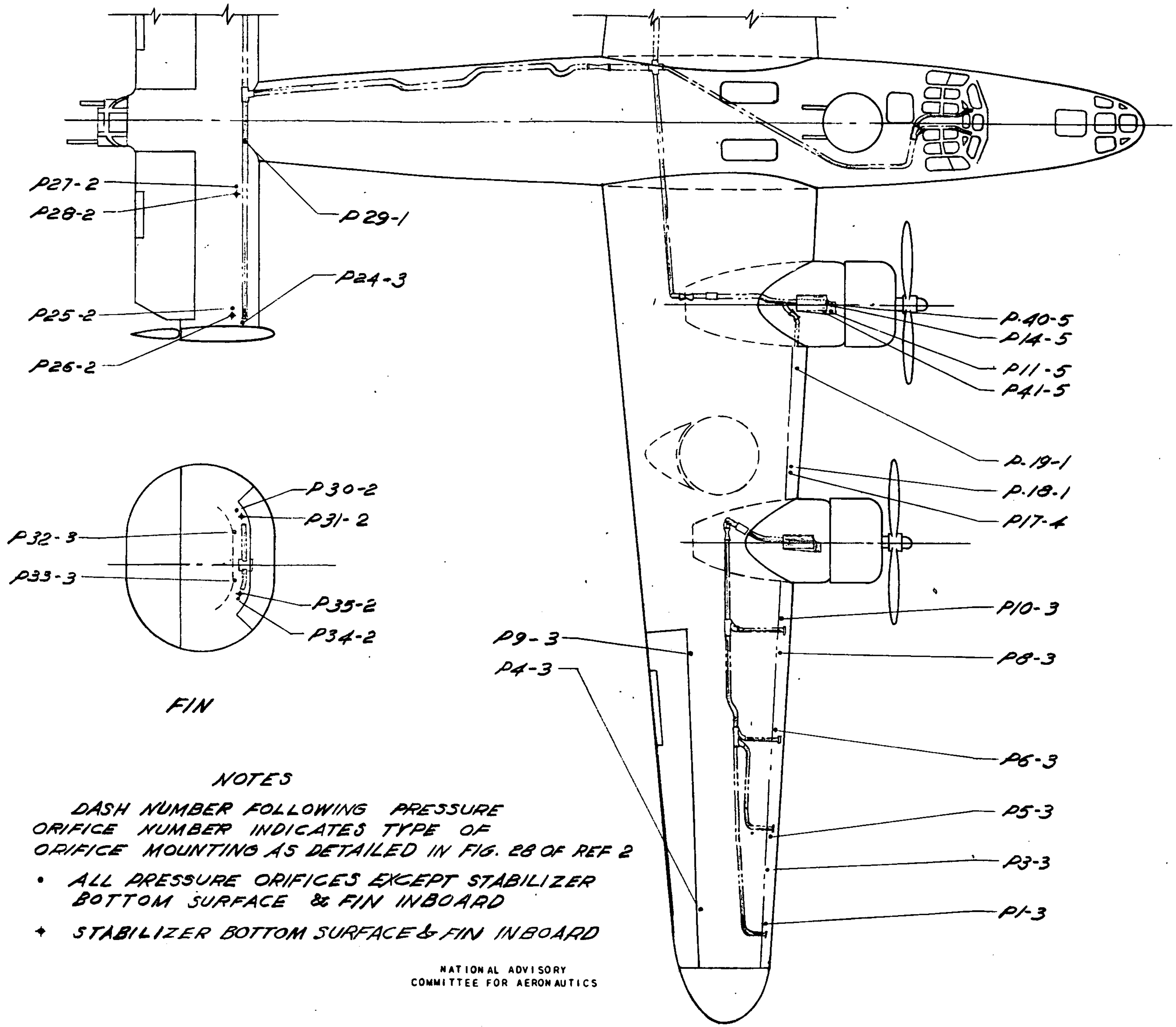

FIGURE 7.- PRESSURE ORIFICE LOCATIONS ON THE XB-24F AIRPLANE EMPLOYED IN TESTS OF THE THERMAL ICE PREVENTION EQUIPMENT.

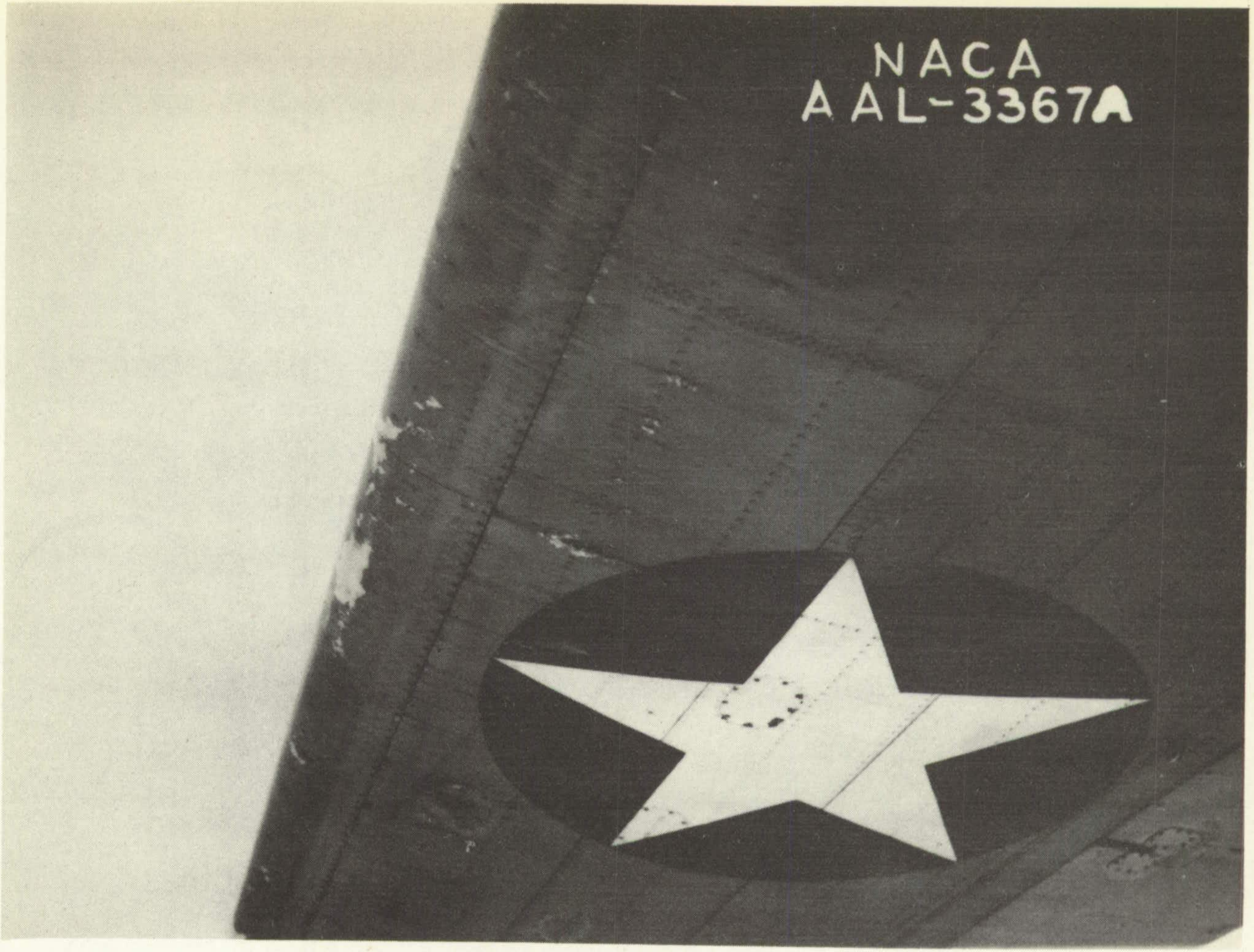

Figure 8.- Lower surface of the right wing outer panel showing the run-back and ice formations aft of the leading edge. Tests 7 and 8.

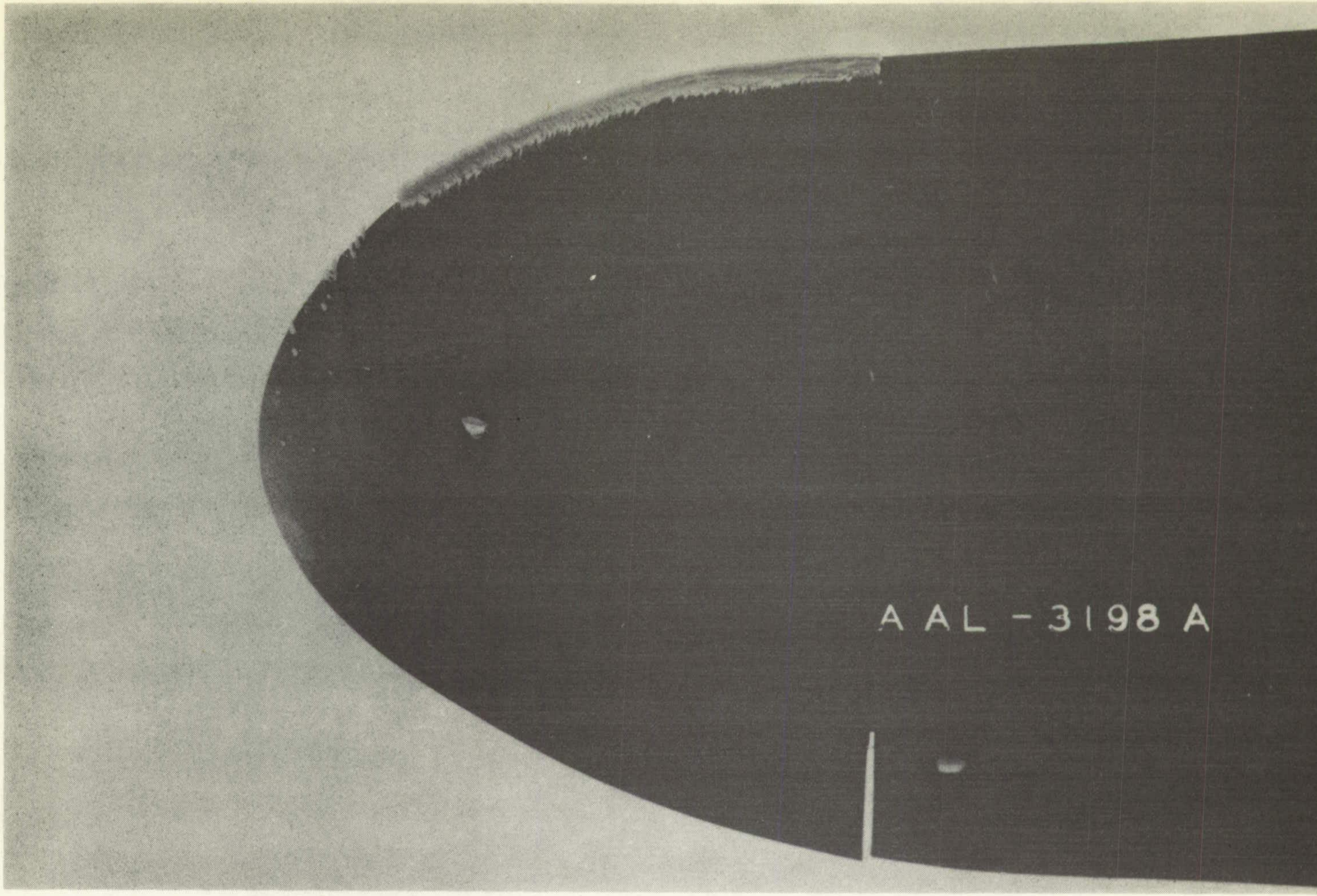

Figure 9.- Rime-ice formation on wing tip compared with clear condition of adequately heated leading edge inboard of tip. Test 13.

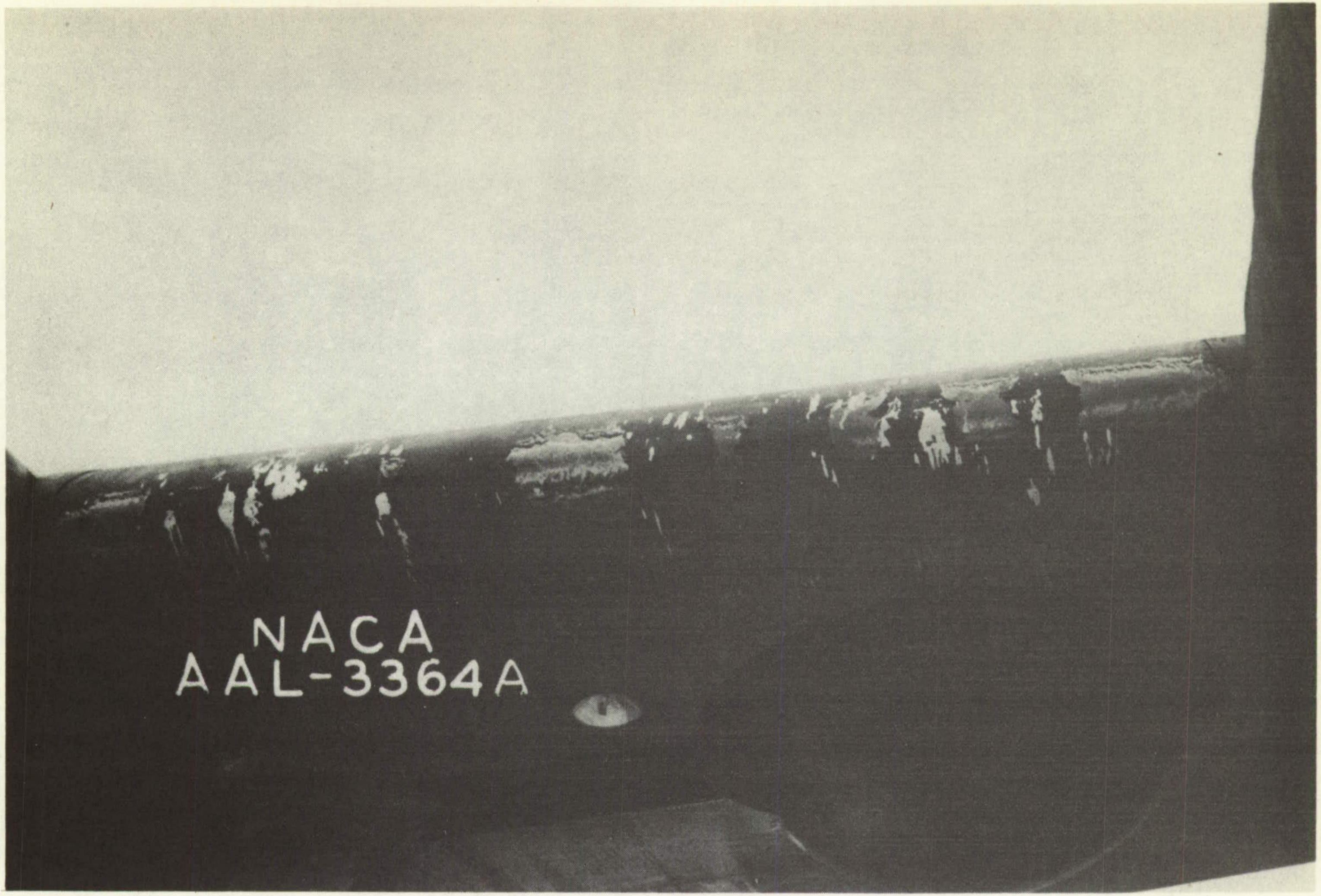

Figure 10.- Left inboard wing panel showing incomplete protection of the leading edge after a flight at cruising conditions. Note run-back aft of leading edge. Extreme white patches are areas of peeled paint. Tests 7 and 8.

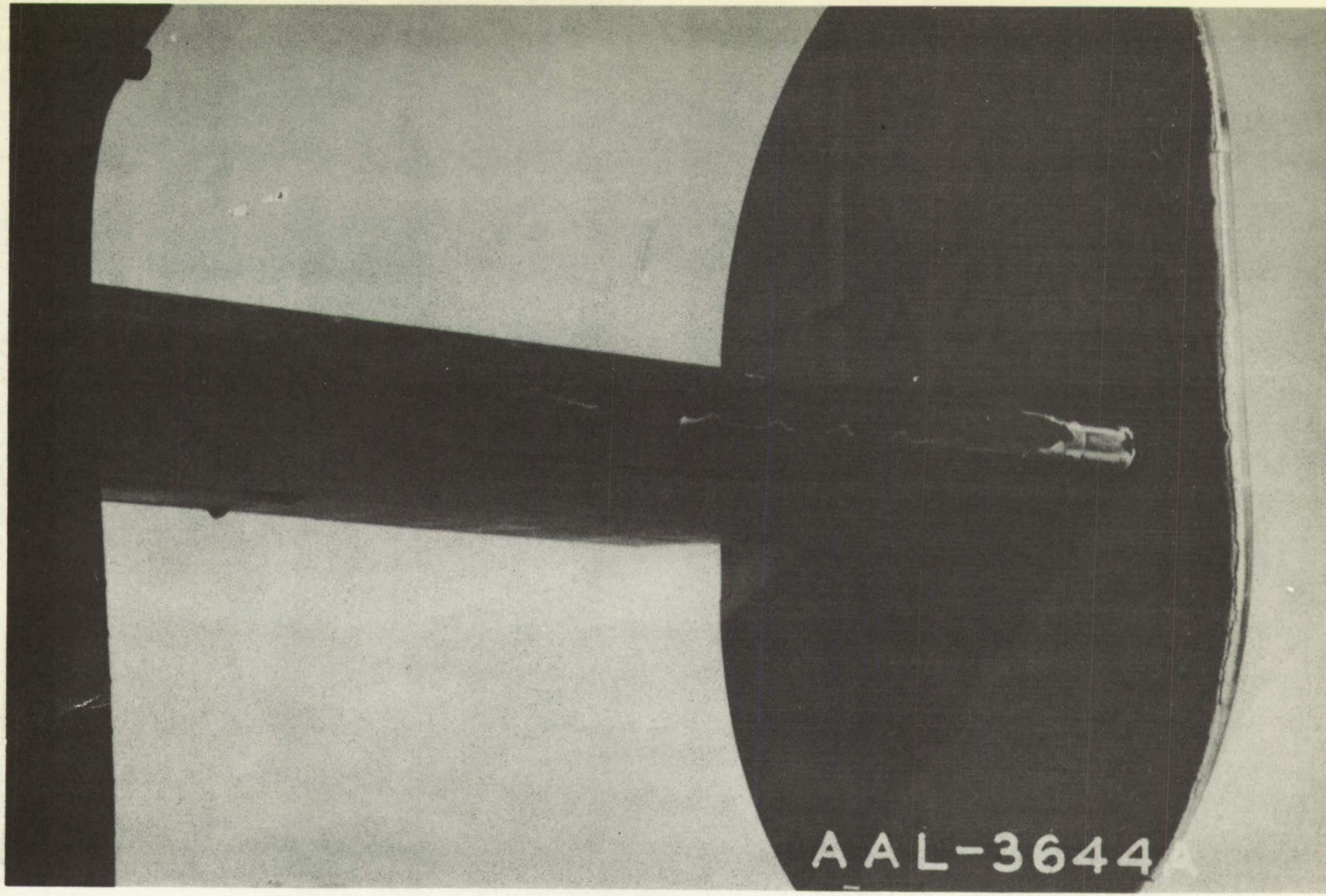

Figure 11. - Rime-ice formations on the left horizontal stabilizer and vertical fin leading edges during a flight in icing conditions at -3° F. Test 14.

Figure 12.- Ice formation at juncture of left horizontal stabilizer and fuselage. Tests 7 and 8.

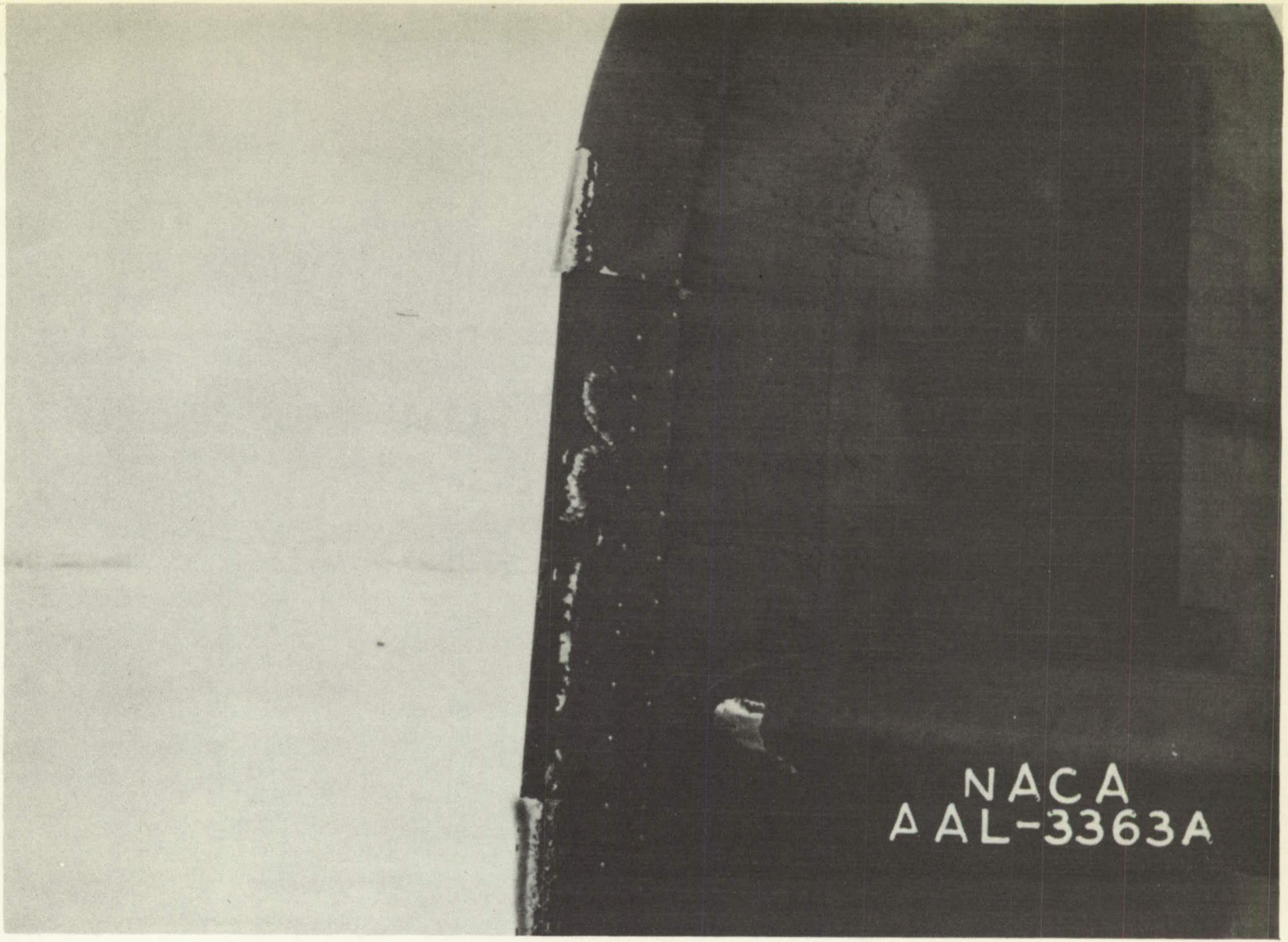

Figure 13.- Ice formations on leading edges of right vertical fin and stabilizer. Tests 7 and 8.

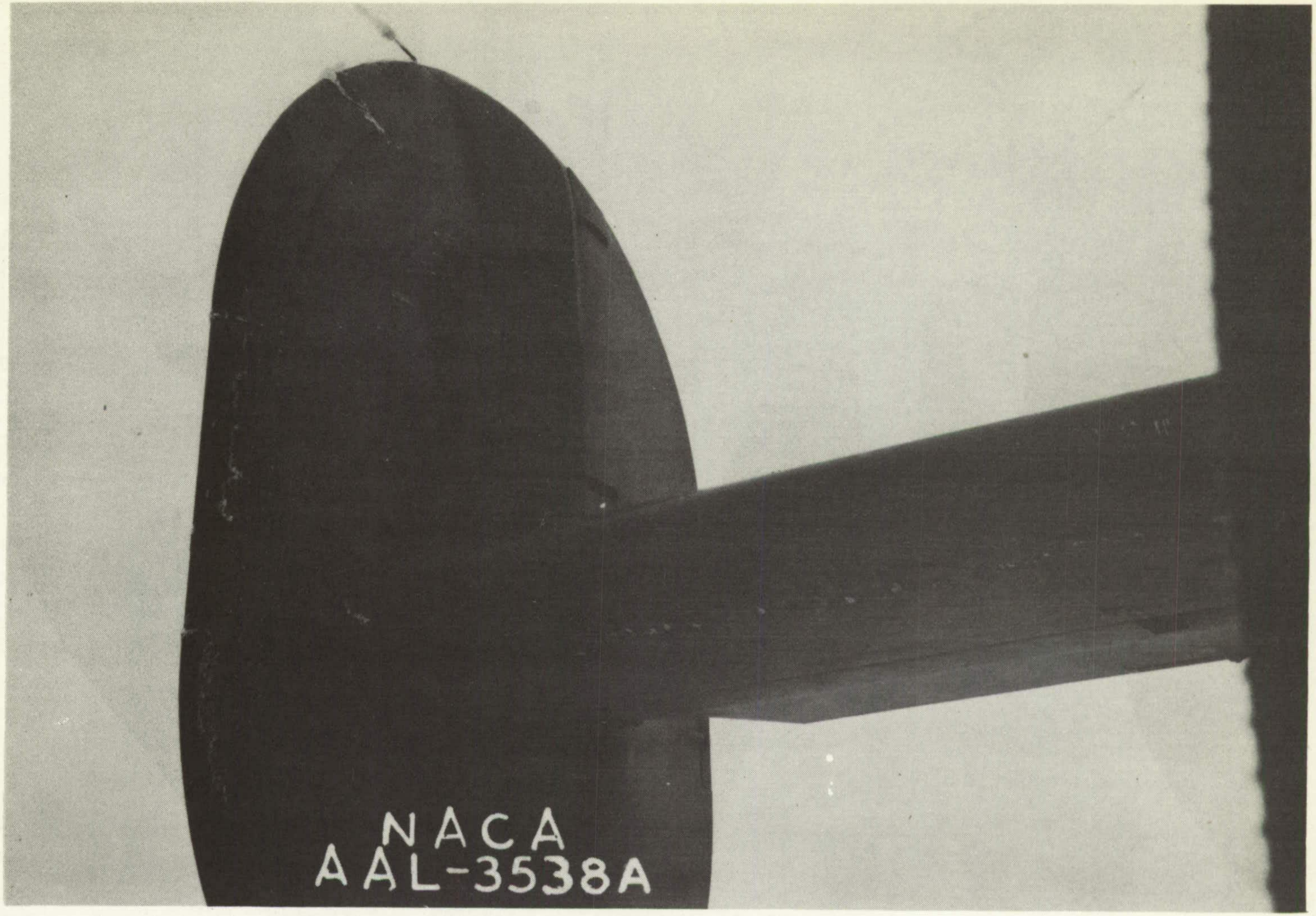

Figure 14.- Right horizontal stabilizer and vertical fin during flight in glaze icing conditions. Test 9.

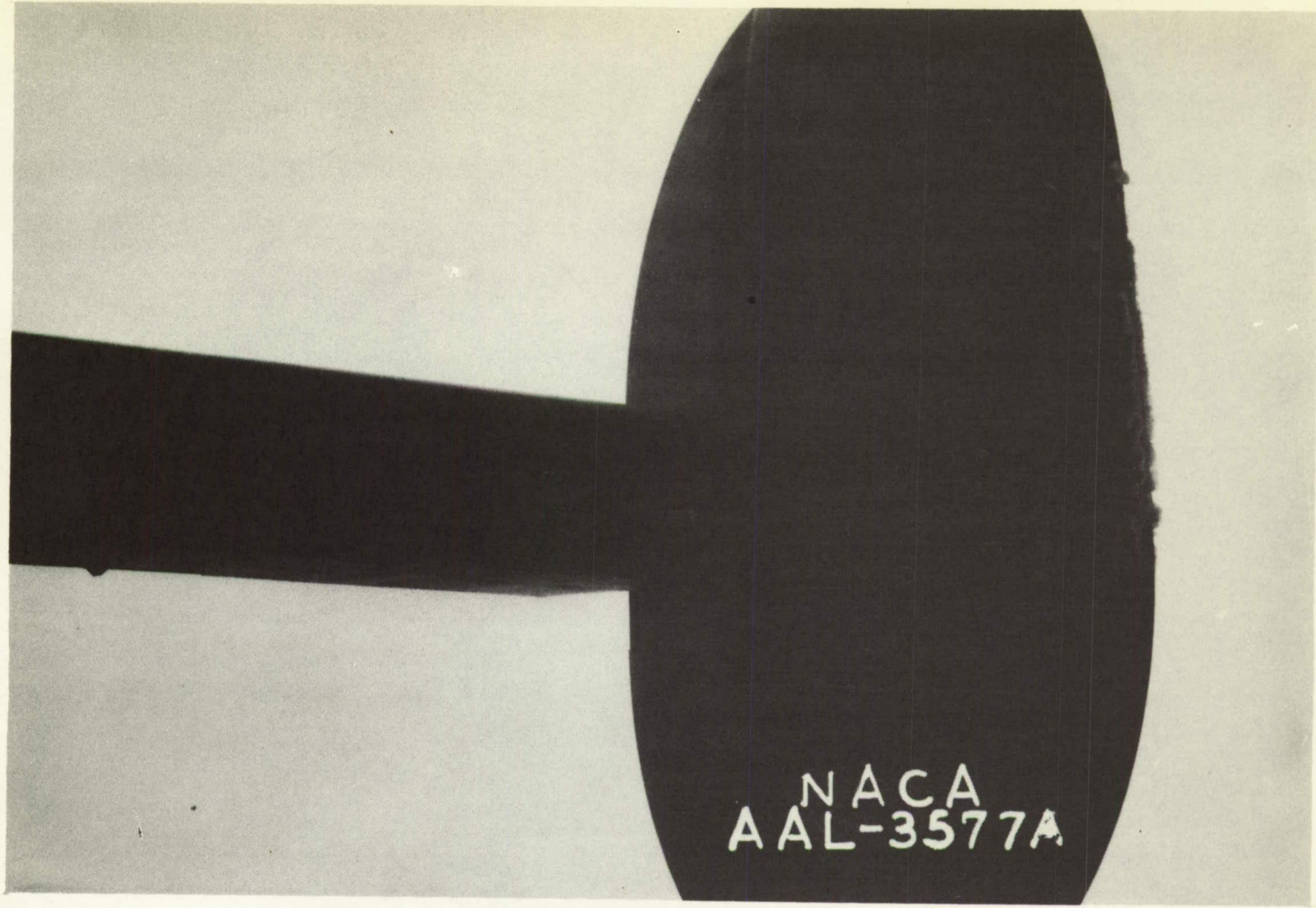

Figure 15.- Left horizontal stabilizer and vertical fin during a flight in rime icing conditions at cruising conditions. Test 12.

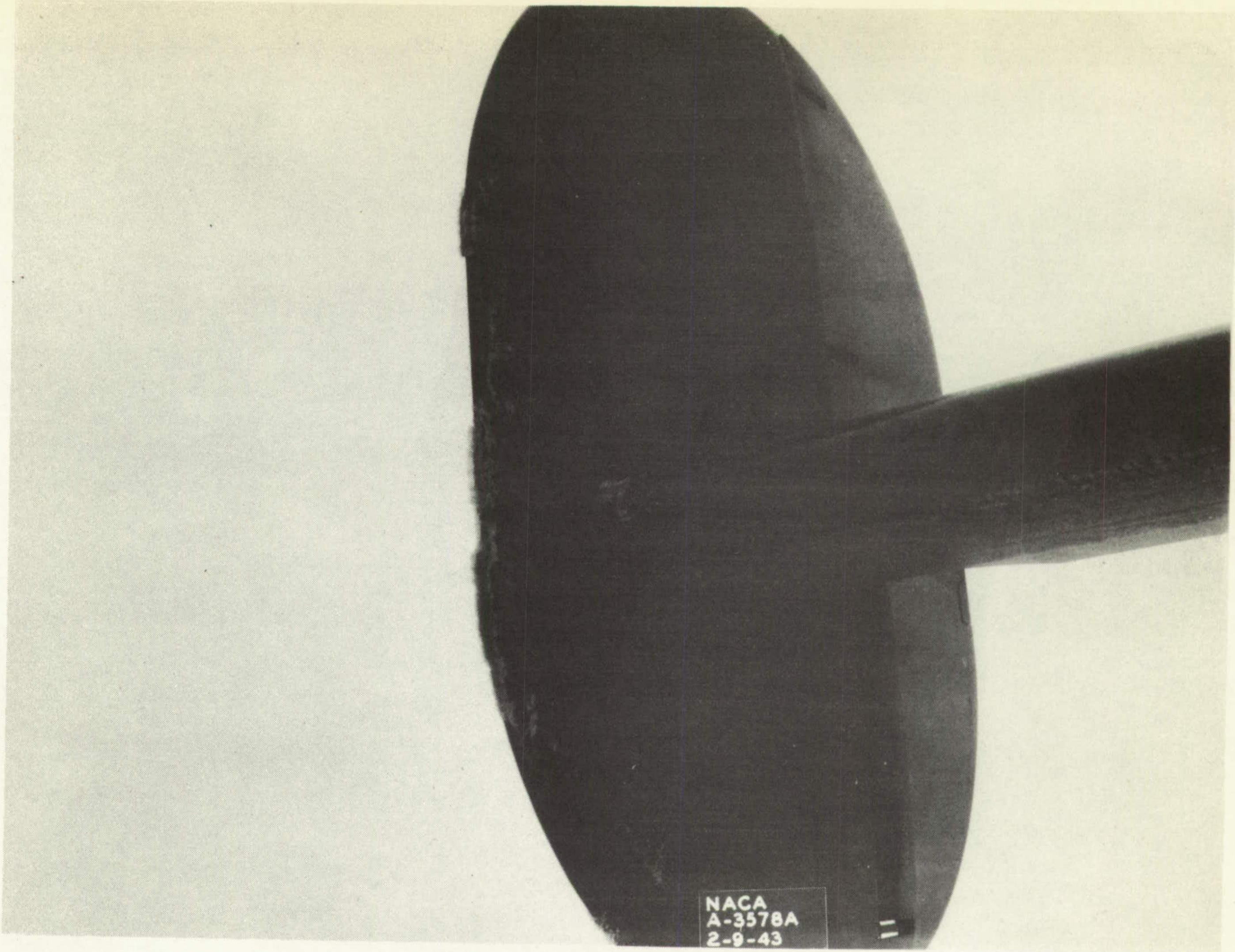

Figure 16. - Right horizontal stabilizer and vertical fin during a flight in rime icing conditions. Test 12.

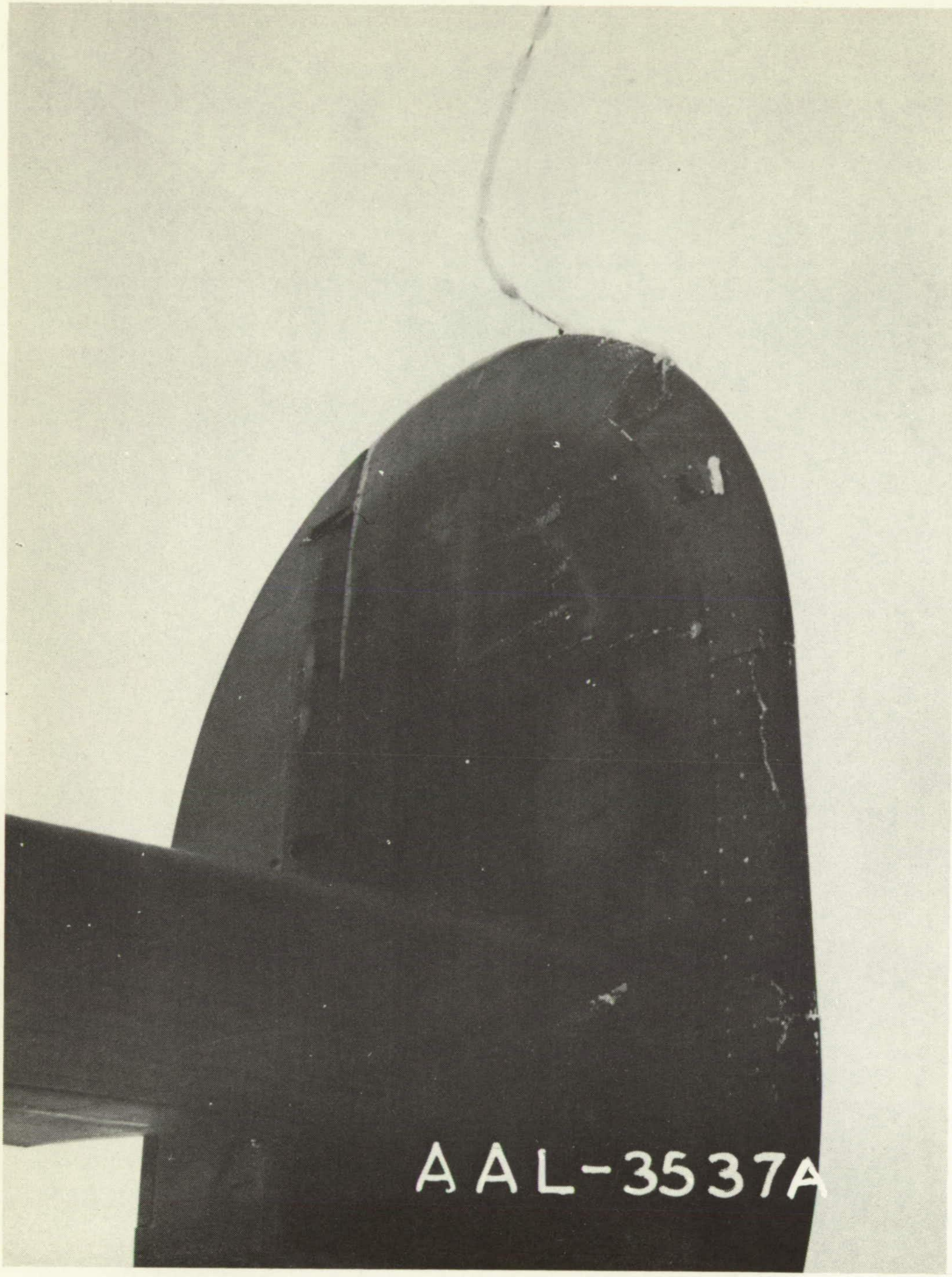

Figure 17.- Left vertical fin during flight in icing conditions. Note ice formations aft of leading edge and on radio antenna. Test 9.

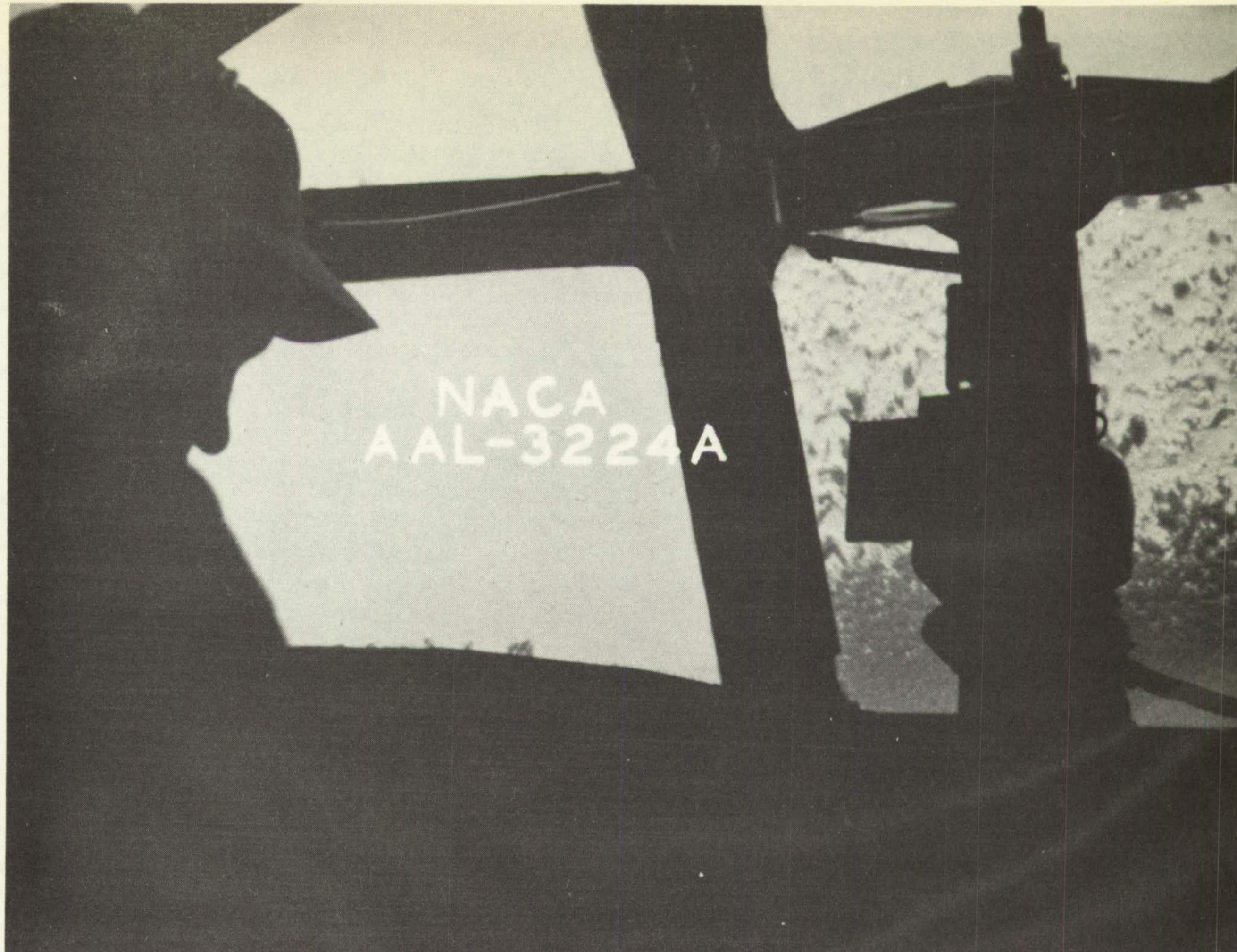

Figure 18.- Pilot's and center windshields during a flight in icing conditions. Note ice formations on unheated center pane. Test 15.

Figure 19. - Copilot's and center windshields during a flight in icing conditions. Test 15.

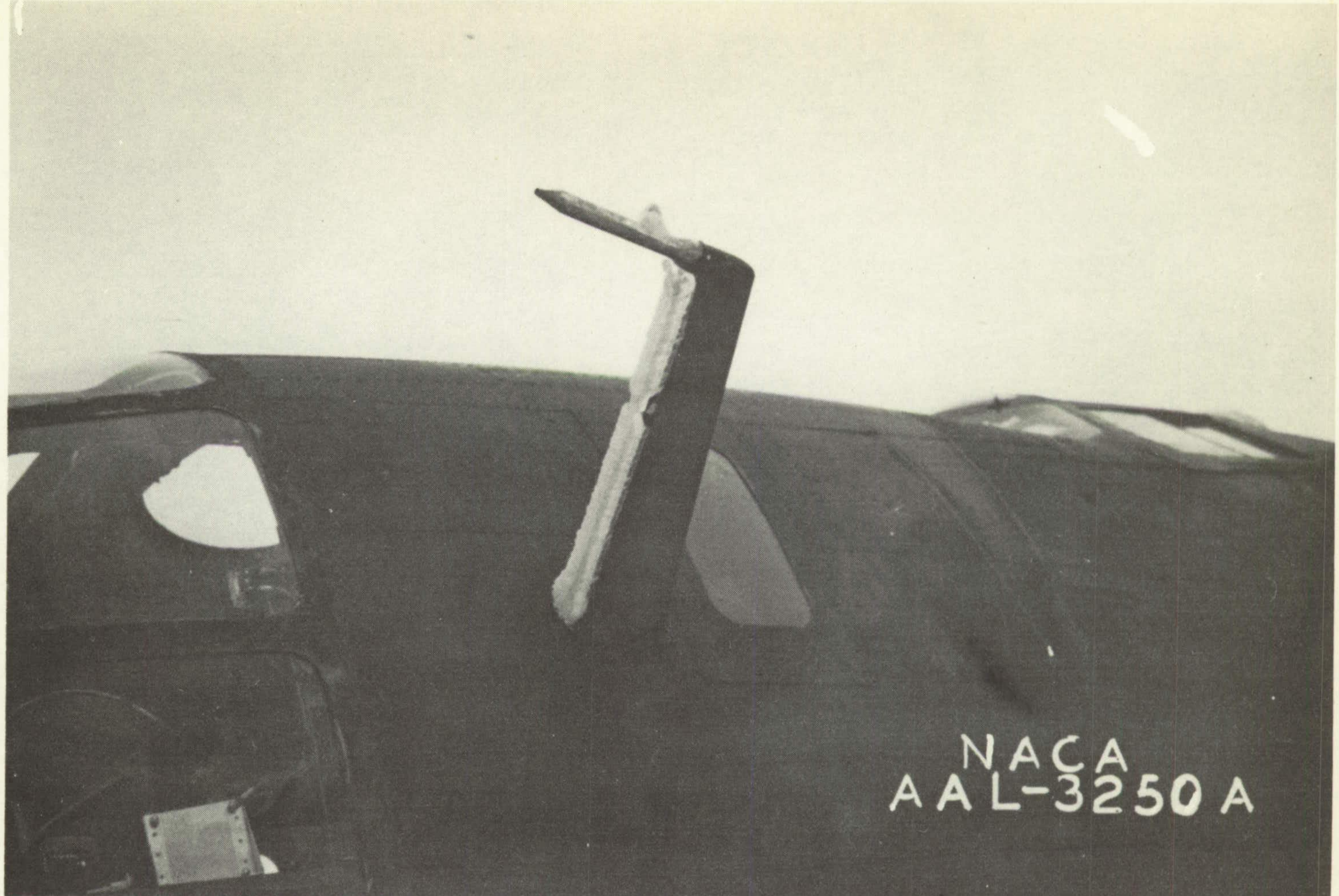

Figure 20.- A rime-ice formation on the left airspeed mast after test 16.

Figure 21.- Rime ice on the radio-antenna anchor insulator at the top of the left vertical fin. Tests 7 and 8.

Figure 22. - A rime-ice formation on the antenna insulator shield. The black streaks through the ice are caused by smoke particles. Tests 7 and 8.

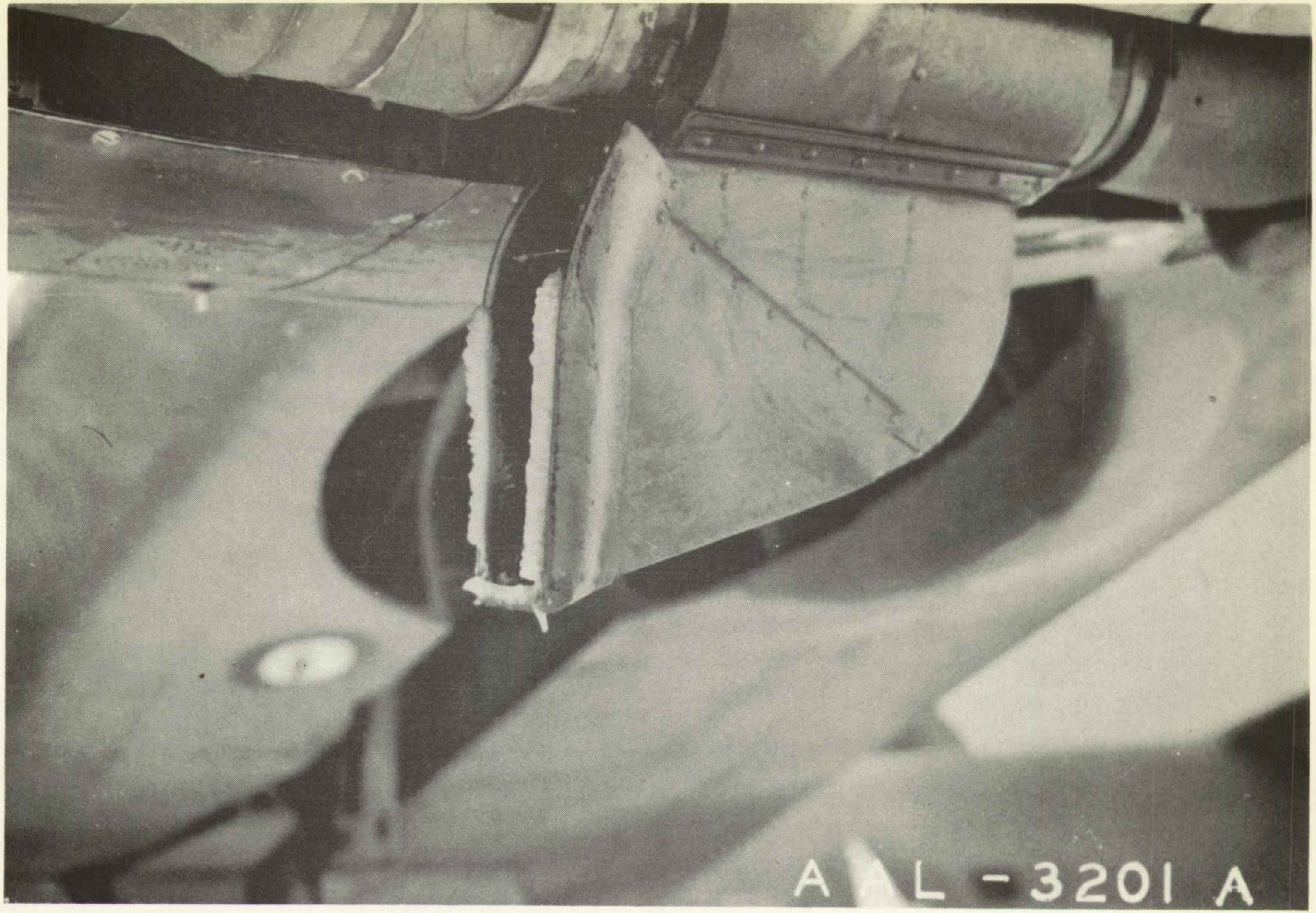

Figure 23.- Rime-ice formations on the heated lips of an air-intake scoop. Test 13.

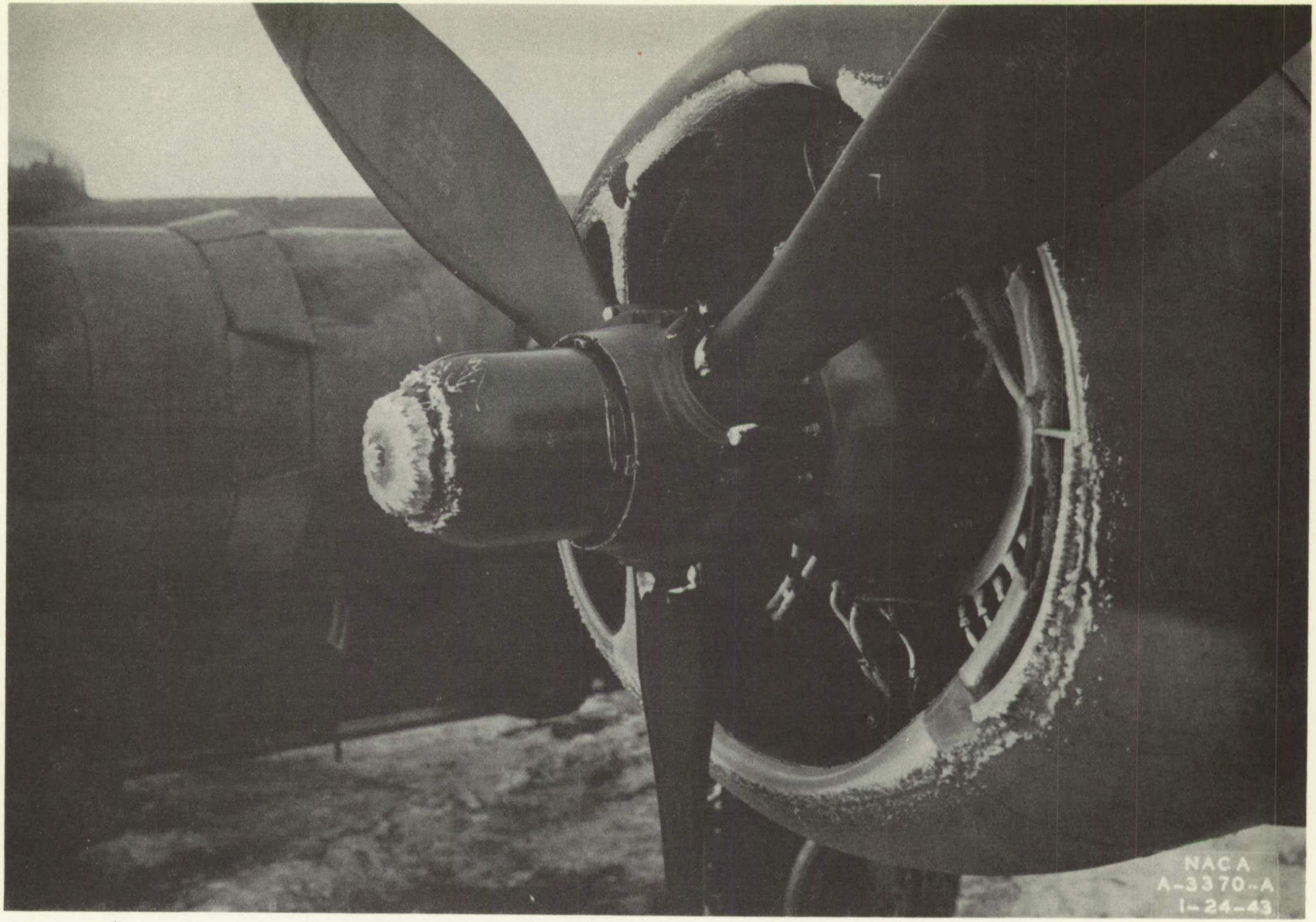

Figure 24. - Rime-ice formations on the propeller spinner and engine-cowl leading edges. Test 7 and 8.

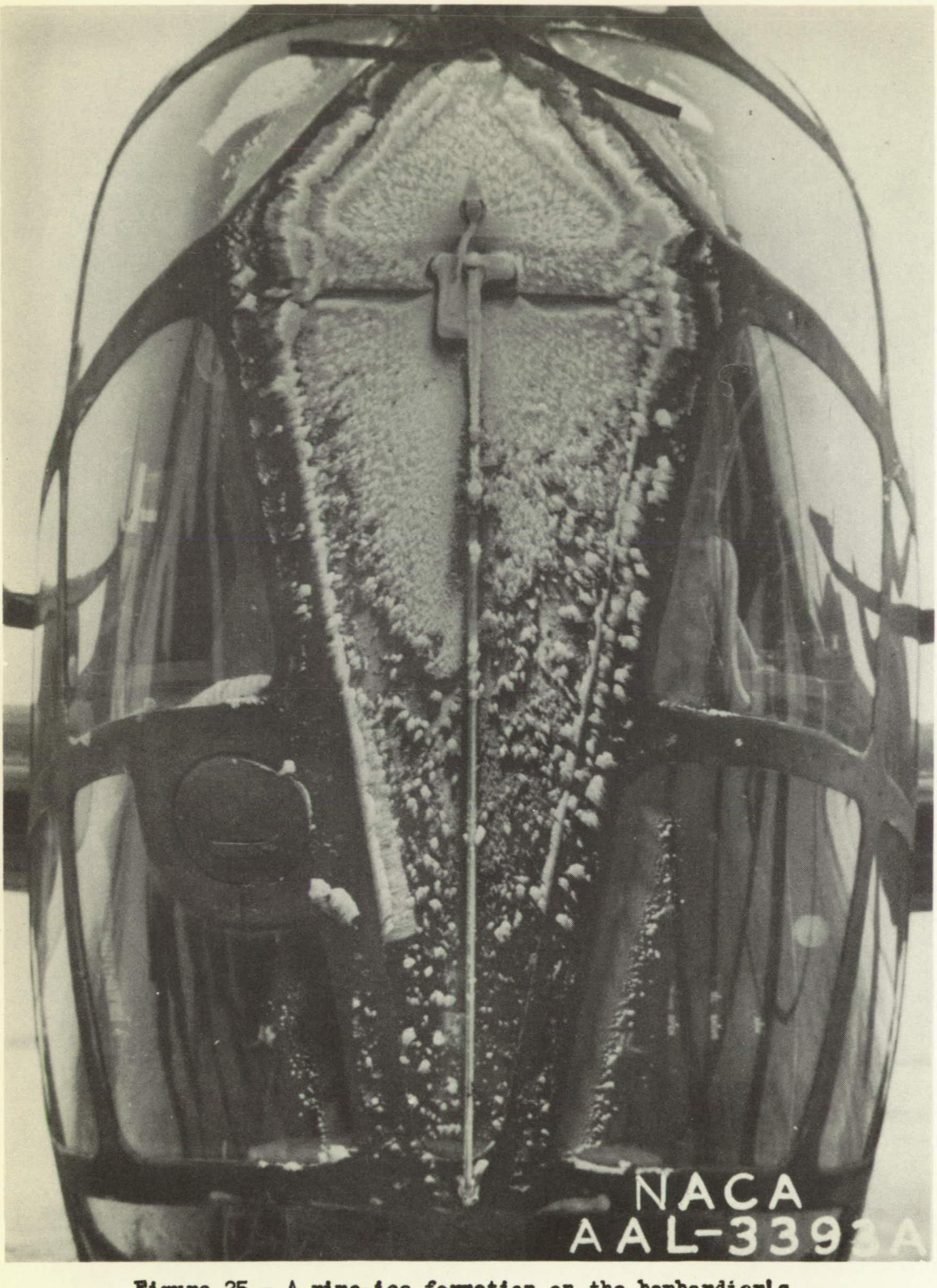

Figure 25.- A rime-ice formation on the bombardier's windshield. Tests 7 and 8.

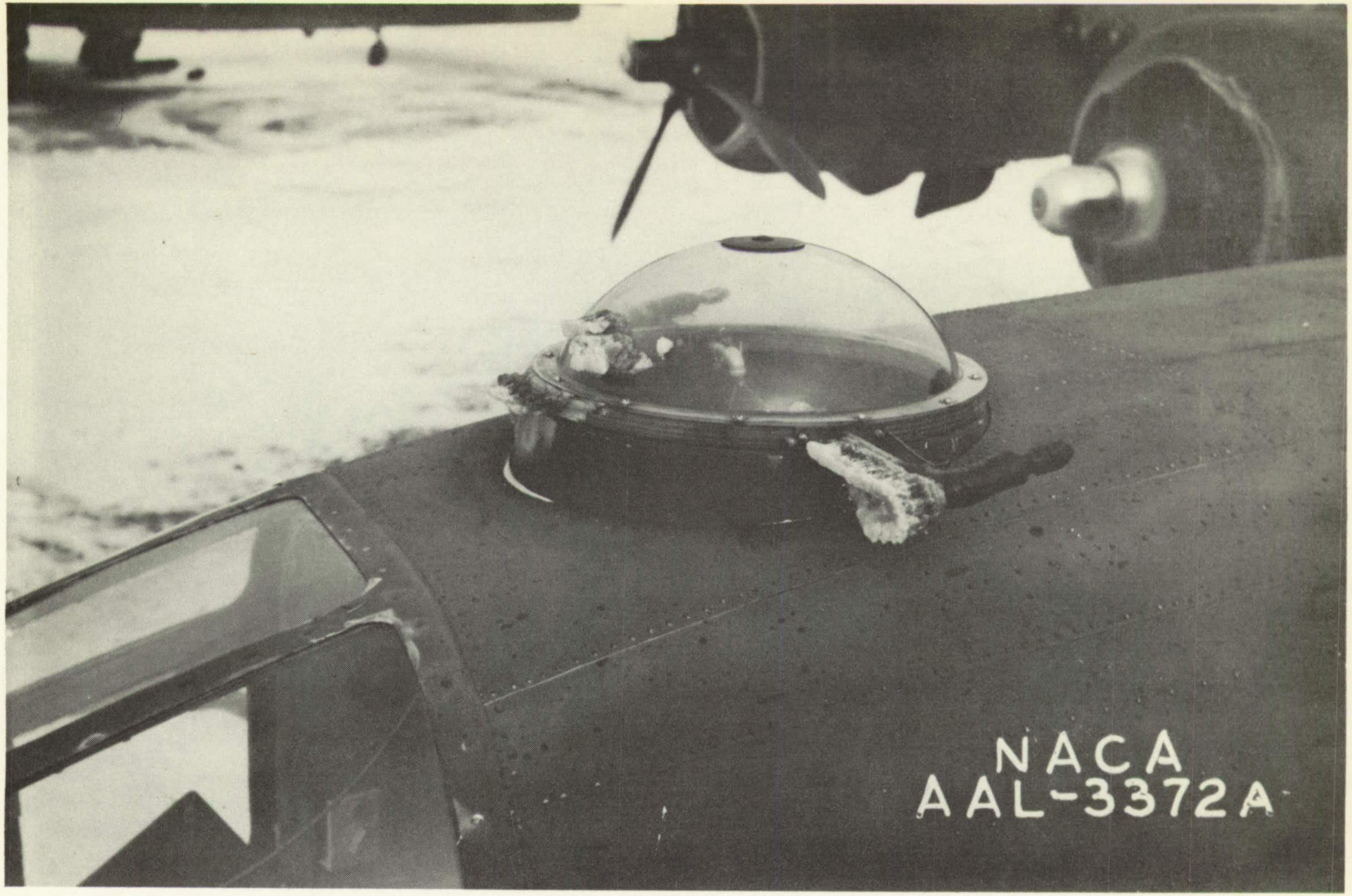

Figure 26.- Rime-ice formations on the astrodome and a protuberance from it. These accretions were about 3 inches thick. Tests 7 and 8.

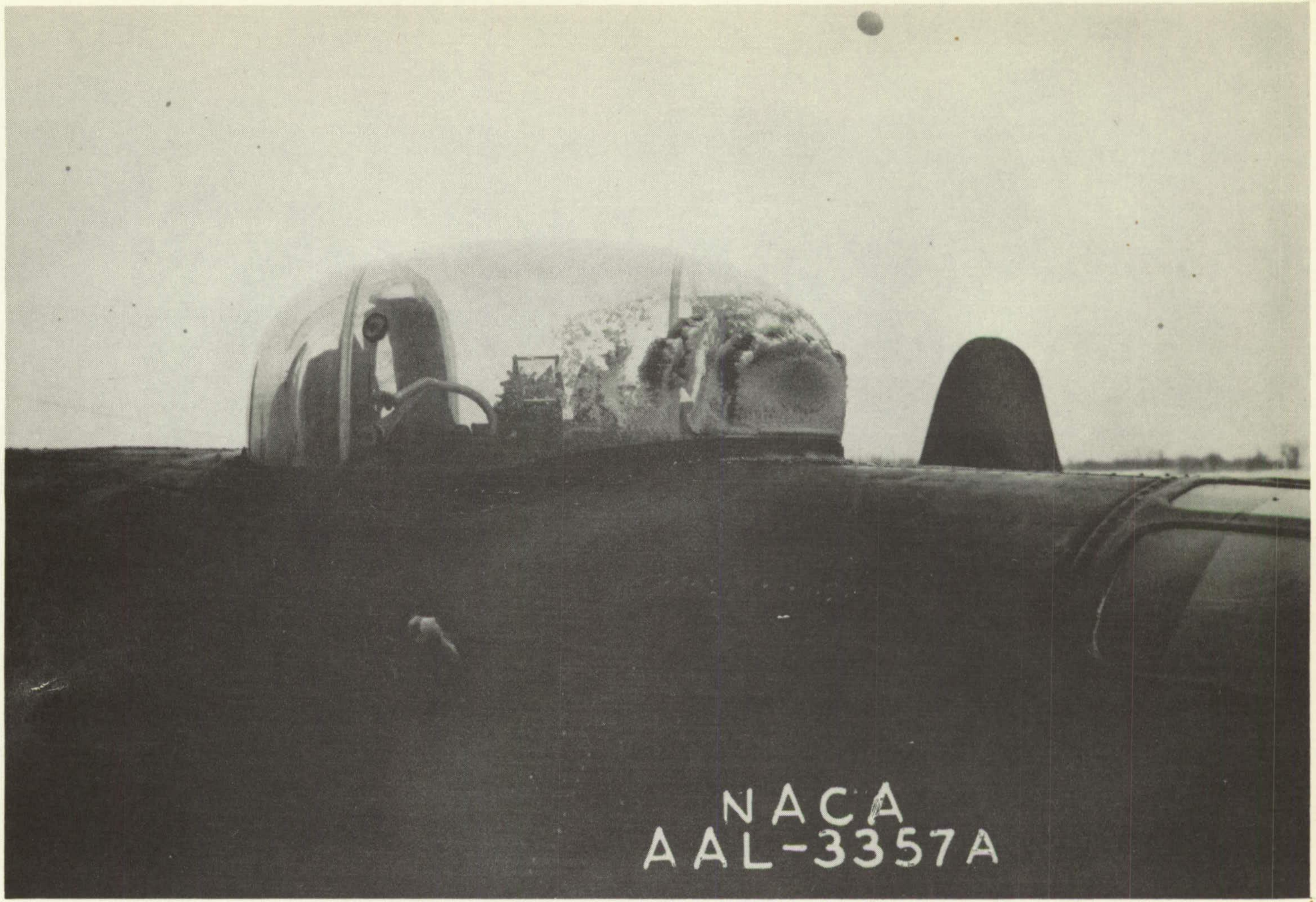

Figure 27.- A rime-ice formation on the top gun turret. Tests 7 and 8.

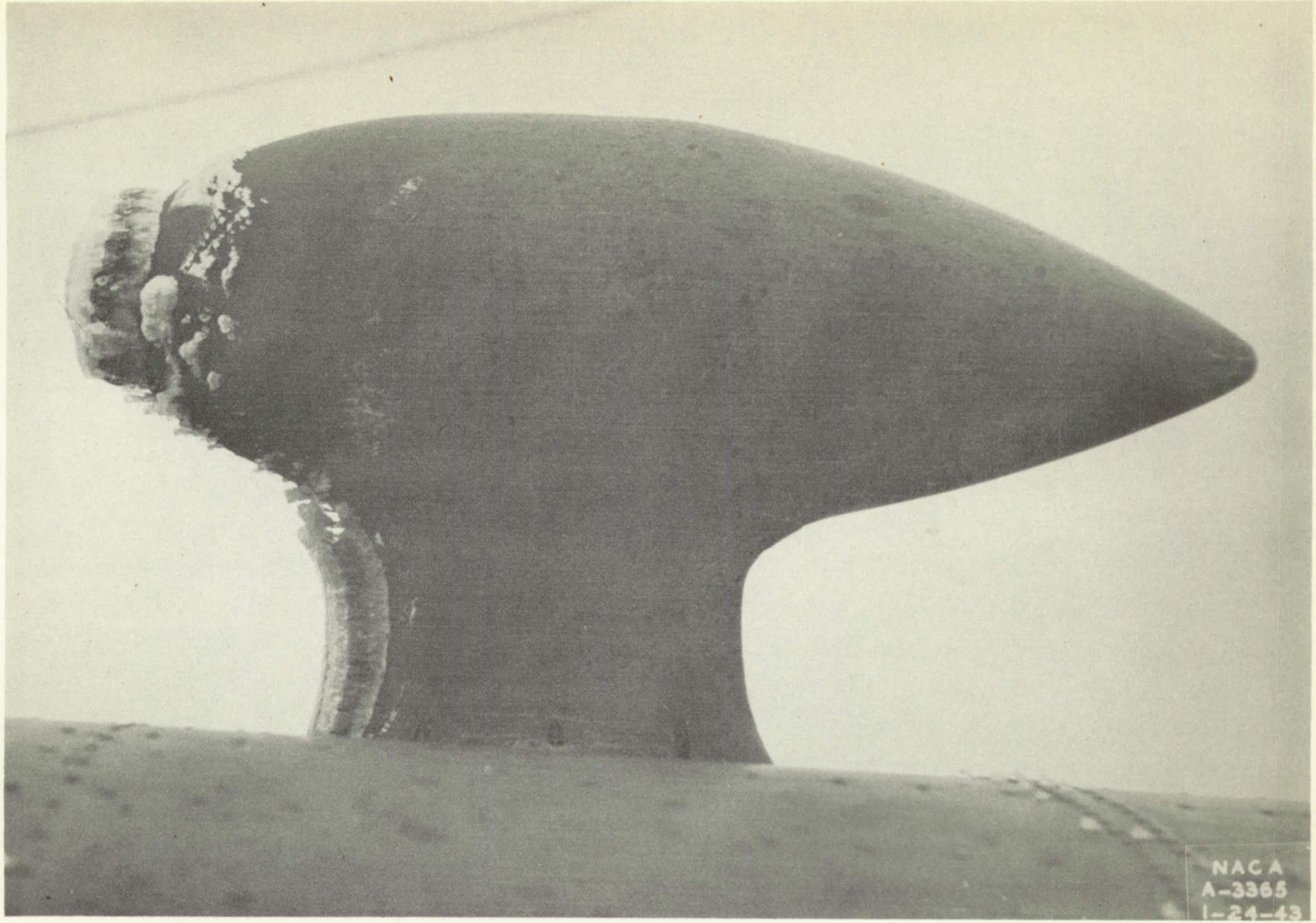

Figure 28. - A rime-ice formation on the loop antenna shield. Tests 7 and 8.

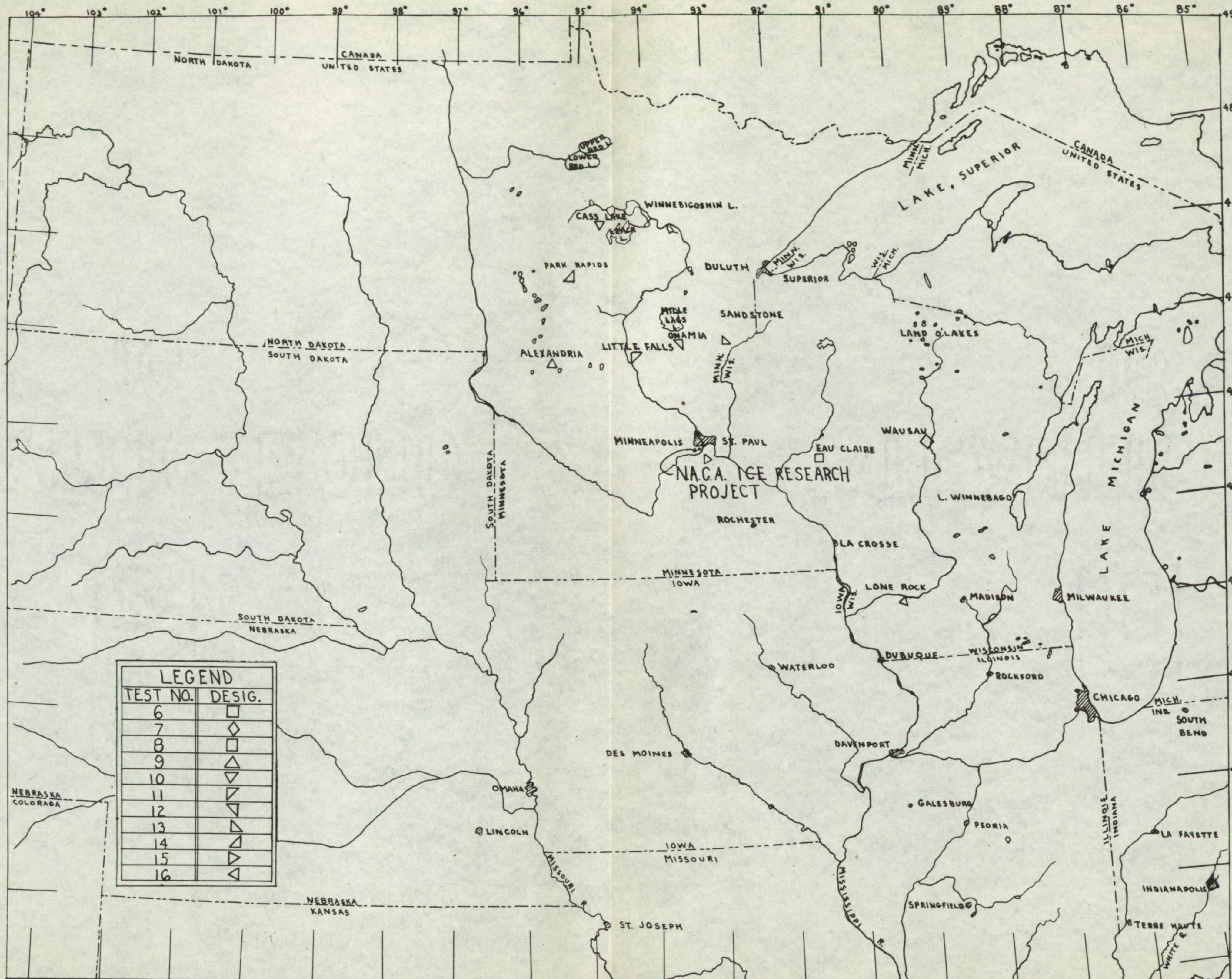

FIGURE 29. - MINNEAPOLIS AREA, SHOWING THE REGIONS IN WHICH THE VARIOUS ICING FLIGHTS WERE CONDUCTED.

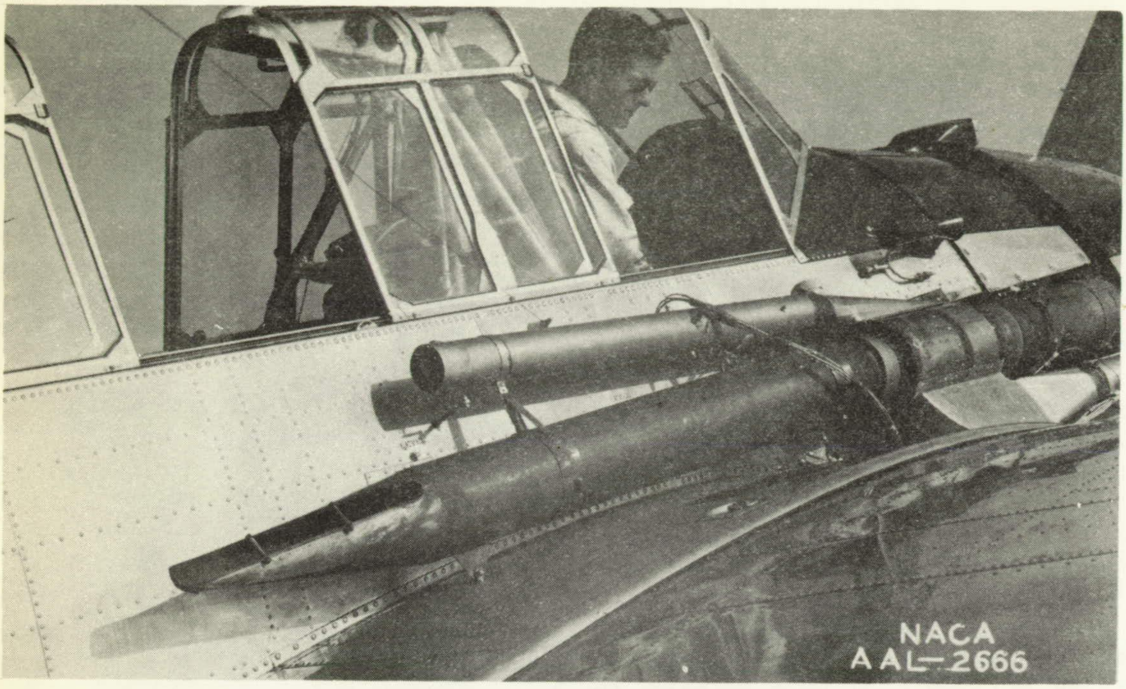

Figure 30.- Installation of one of the XB-24F airplane exhaust-gas-to-air heat exchangers on an O-47A airplane for performance tests.