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FLIGHT TESTS OF SEVERAL EXHAUST-GAS-TO-AIR HEAT EXCHANGERS IN A B-17F AIRPLANE

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MEMORANDUM REPORT

for the

Materiel Command, U.S. Army Air Forces

FLIGHT TESTS OF SEVERAL EXHAUST-GAS-TO-AIR HEAT EXCHANGERS IN A B-17F AIRPLANE

By Bonne C. Look and James Selna

SUMMARY

Seven exhaust-gas-to-air heat exchangers were flight-tested at the Ames Aeronautical Laboratory of the National Advisory Committee for Aeronautics on a B-17F airplane to determine their performance characteristics and to investigate their flame-suppression qualities. The tests were conducted to secure performance data of heat exchangers which might be suitable for use in the thermal ice-prevention and cabin-heating systems of the heavy bomber-type airplanes.

For this investigation, the performance characteristics of the heat exchangers have been defined as the air-flow rate, air-temperature rise, rate of heat transfer, and the air- and exhaust-gas-side pressure drops. The information obtained is presented in tables which include the recorded data and the general performance characteristics of the heat exchangers evaluated from the recorded data. The design requirements of heat exchanger installations for a typical four-engine bomber cabin-heating and thermal ice-prevention system are presented and compared with the performance of the tested exchangers. The flame-suppression qualities of the exchanger were investigated by visual observation, and the results are presented in tabular form. A limited amount of information was secured relative to the effect of a heat exchanger, installed between the engine and the turbine supercharger, on the supercharger speed and angular position of the waste-gate butterfly valve.

The results of the performance tests indicated that under design test conditions the rate of heat transfer specified for the outboard-nacelle heat-exchanger installations would probably be realized by the units tested in those nacelles. It is questionable if any of the exchanger installations tested would have satisfied the rate-of-heat-transfer requirement for the inboard-nacelle installations at design test conditions. For all installations it was found that the air-side flow resistance, indicated by the total pressure drop across the heat-exchanger installations, was high and resulted in low air-flow rate and in most cases high air-temperature rise.

The results of the flame-suppression investigation showed the glowing of the exhaust stack and turbine-supercharger parts to be more visible than the exhaust-gas flaming for the conditions tested. The data obtained on the effect of a heat-exchanger installation on the operation of a turbine supercharger indicated that the critical altitude of the supercharger for rated engine-power conditions was not affected by the heat-exchanger installation. Also, for a given manifold pressure, greater closure of the waste-gate valve was required with the exchanger installed than without the exchanger. The investigation was limited in scope and did not provide sufficient information for final conclusions regarding the effect of heat-exchanger installations on supercharger performance.

INTRODUCTION

For the past several years, an extensive investigation of exhaust-gas-to-air heat exchangers has been conducted by the NACA at the Ames Aeronautical Laboratory and at the University of California as a part of a general research program on the development of thermal ice-prevention equipment for airplanes. The results of a large portion of the research conducted at Ames Aeronautical Laboratory are presented in reference 1, wherein reference is also made to the work done at the University of California. These preliminary researches were of a general nature to investigate the performance of the exchangers and the feasibility of their use in thermal ice-prevention equipment.

The purpose of the present investigation was to determine the performance of various types of exhaust-gas-to-air heat exchangers with respect to their adaptability to a production version of thermal ice-prevention and cabin-heating equipment for a heavy bomber type airplane. The tests were conducted on the B-17F airplane, for which the Ames Aeronautical Laboratory had designed, installed and flight-tested a thermal ice-prevention system (references 2 and 3). Performance data were obtained for each heat exchanger for similar flight conditions. The performance tests were supplemented by night flights during which the degree of flame suppression provided by the different exchanger installations was observed. A limited amount of information was obtained on the effect of a heat-exchanger installation on the turbine-supercharger operation.

EQUIPMENT

Description

The B-17F airplane in which the seven exhaust-gas-to-air heat exchangers were tested is shown in figure 1. The seven heat exchangers tested were all-primary surface units of three general types: (1) tubular, (2) plate, and (3) flute.

One of the original heat exchangers used in the thermal ice-prevention-system of the B-17F airplane, employed as a test airplane for the present tests is shown in figure 2. The exchanger was of the cross-flow type and consisted of a stainless-steel shell with longitudinal folds to form fins on the exhaust-gas side, and copper strips inserted in the longitudinal folds and cut to provide pin fins on the air side. This heat exchanger is described in detail in reference 2 and performance data may be found in references 2 and 3.

The two tubular-type heat exchangers were cross-flow in design, the air flowing across the tubes and the exhaust gas through the tubes. These exchangers are designated as heat exchangers 1 and 2 and are shown in figures 3 to 6 inclusive.

The three plate-type heat exchangers tested were also cross-flow in design, and consisted of a number of alternate air and gas passages separated by thin plates. For two of these exchangers, designated as 3 and 4, the separating plates were flat, and the two exchangers differed only in the number of air passages, exchanger 3 having nine and exchanger 4 having eleven. The additional air passages in exchanger 4, one on each side, were provided because it was doubtful if the outside plates of exchanger 3, which formed one side of a gas passage, would be sufficiently cooled to prevent buckling and distortion. These two heat exchangers are shown in figures 7 to 10, inclusive. In the case of the third plate-type heat exchanger, designated as heat exchanger 5 and shown in figures 11 and 12, the separating plates were corrugated. The corrugated plates were assembled in such a manner that a straight passage, diamond-shaped in cross section, was presented for exhaust-gas flow while the air was caused to flow through a narrow, constant-gap, winding passage.

The two flute-type heat exchangers were parallel-flow in design, and consisted of a series of alternate air and gas trapezoidal ducts which formed a cylindrical heat exchanger with a hollow core. These heat exchangers, designated 6 and 7, are shown in figures 13 to 17. Heat exchanger 6 was provided with a removable plug located in the hollow core of the exchanger on the exhaust-gas side for the purpose of directing all of the exhaust gas through the trapezoidal gas passages. (See fig. 15.)

Installation

The various heat-exchanger installations are described in detail because in determining a heat exchanger for use in bomber-type airplanes it is important to consider the ease of installation of the unit, and because the performance of a heat exchanger depends to a great extent on the manner in which it is installed in the airplane. In figure 18 the heat exchangers are listed according to the nacelle in which they were tested.

All the heat exchangers were designed to replace the straight, removable section of the exhaust-stack system between the ball joint and the turbine supercharger. These removable sections were about 24 inches long for nacelles 1 and 4, and 38 inches long for nacelle 3. Heat exchangers 1, 3, 4, 5, and 6 were designed for installation in nacelles 1 or 4, and heat exchanger 7 was designed for installation in nacelle 3. Heat exchanger 2 was not designed for a specific nacelle and was tested in nacelle 3.

In general, each heat-exchanger installation consisted of the air inlet scoop, heat-exchanger shroud, air outlet header, and the necessary ducting to direct the heated air to the point of discharge. Since the tests were conducted to determine the performance of the heat exchangers and not of the thermal ice-prevention equipment, the heated air from the outboard exchangers was discharged overboard at the top of the nacelles and the air from the inboard exchanger was discharged through a louver in the upper surface of the wing. Alterations to the nacelles were necessary in order to accommodate the various heat exchangers and to provide an outlet for the heated air. The majority of the alterations were confined to the exhaust shroud, defined as that portion of the nacelle structure (formed of corrosion-resistant steel sheet) which shields from the remainder of the nacelle heat and exhaust gases from the exhaust stack. The installation of heat exchanger 1 in nacelle 1 required a cut-out in the exhaust shroud for the heated-air outlet as shown in figure 19. The installation of exchanger 6 in nacelle 1 necessitated an enlargement of the exhaust shroud and, also, a cut-out for the heated-air outlet. (See fig. 20.)

Considerable alteration to nacelle 3 was necessary for the installation of heat exchanger 2. The exhaust shroud was altered to accommodate the heat exchanger and provide for the heated-air outlet as shown in figure 21. No major alteration of the exhaust shroud was required for the installation of heat exchanger 7 as the original shroud of nacelle 3 was used and a heated-air outlet provided as shown in figure 22. In the case of nacelle 4, one alteration to the exhaust shroud was sufficient for the installation of all three of the exchangers tested in that nacelle. This alteration is shown in figure 23. The top of the shroud was left open for the heated-air outlet.

Details of the heat-exchanger installations for the performance tests are given in figures 24 to 45, inclusive. These installations were for test purposes of limited duration and do not necessarily represent a satisfactory service installation. In the installation details the heat-exchanger shroud is defined as that portion of the system which restricts the air flow to the exchanger passages between the inlet scoop and the outlet header. For example, in the case of exchangers 1 and 2, the exchanger shrouds are considered to be the additions to the exchangers as is evident from a comparison of figures 3 and 5 with figures 4 and 6, respectively. For exchangers 6 and 7, the exchanger shroud consisted of the exhaust-stack shroud on one side of the exchanger and a continuation of the air inlet scoop on the other side. The space between the exhaust stack and the shroud was sealed, in front of and behind the heat exchanger, with rings formed of stainless steel which have been referred to as dams. (See figs. 27, 28, 33, and 34.) The air-tempering system shown in figures 33 and 34 was not installed until after the performance tests. In preliminary flights with exchanger 6, the plug in the exhaust-gas core was found to produce an excessive temperature rise of the air and was, therefore, removed for the performance tests.

For the flame-suppression tests, the installations of all the heat exchangers except 6 and 7 were the same as for the performance tests. In order to increase the quantity of heat removed from the exhaust gas for heat exchangers 6 and 7, the rear dams were removed, thus allowing the air to discharge through this opening in addition to the regular discharge. Furthermore, in the case of exchanger 6, the gas-side plug which had been removed for the performance tests was reinstalled.

After the performance and flame-suppression tests of the heat exchangers had been completed, three of the heat exchangers which appeared to be most readily adaptable for use were installed in nacelles 1, 3, and 4 for service testing. The preliminary investigations of the service-test installation, hereafter referred to as the final installation, were conducted at the Ames Aeronautical Laboratory and form a part of this report.

A valve assembly was installed in the heated-air-outlet system of the final installations which provided for directing the heated air to the ice-prevention system (from nacelle 1 to the left-wing outer panel, from nacelle 3 to the empennage, and from nacelle 4 to the right-wing outer panel) or overboard. The valves were actuated by electric motors and could be operated in flight. During the preliminary tests of the final installations the heated air was discharged overboard; however, the valves were included in the installations in order that the heated air could be directed to the ice-prevention system during the service tests.

The final revisions to heat exchanger 5 and the installation details are shown in figures 46 to 51, inclusive. The revised shroud design shown in figure 46 provided an increased air passage around the sides of the exchanger and freedom of motion between the shroud and exchanger. (See Section C-C, Fig. 48.) The new air inlet scoop (fig. 51) extended forward to the rear edge of the cowl flaps, and a baffle (or glow shield) was installed inside the scoop in order to reduce the possibility of oil and explosive gasoline vapors entering the system with the air and to decrease the visible glow of the exhaust system to a minimum. An opening was provided in each side of the scoop between the glow shield and the exhaust stack to provide for circulation of cooling air against the exhaust-stack assembly.

During the performance tests, exchanger 7 had developed cracks in the flutes at the forward beaded ring, and some of the spot welds attaching the flutes to the circumferential rings had failed. For the final installation a new unit was constructed, shown in figure 52, which was of the same design as the original exchanger 7, but was fabricated somewhat differently in an effort to eliminate the failures noted above. A new type circumferential band was designed to provide less restriction to expansion of the exchanger, and the flutes of the new heat exchanger were formed to eliminate the welded joint at the innermost edge of each flute, which simplified the joining of the flutes at the end bands of the heat exchanger.

The final heat-exchanger installation in nacelle 3 did not require alterations to the exhaust shroud, but a cold-air-tempering system was installed in order to decrease the temperature of the air supplied to the ice-prevention system. This air-tempering installation, shown in figures 33, 34, and 53, consisted of an air inlet scoop located on the nacelle above and aft of the heat-exchanger scoop, a duct to direct the air to the heat-exchanger air outlet header, and a valve to control the amount of cold air admitted into the heated-air stream. The valve position was set before flight because no means was provided to adjust the valve during flight. The valve assembly to control the direction of heated-air flow was located in the wing near the overboard discharge louver (figs. 35 and 54). The final installation of heat exchanger 7, ready for flight-testing, is shown in figure 55.

Heat exchanger 3, shrouded as shown in figure 56, was installed in nacelle 4 for service testing. The shroud was added to the heat exchanger to provide two additional air passages, approximately five-eighths inch wide, in order to increase the air-flow rate through the unit. The installation of this exchanger was similar to that of exchanger 5 in nacelle 1 and is shown in figures 57 to 60.

Instrumentation

The instrumentation of the heat-exchanger installations provided for the determination of the air-flow rate, temperature rise, and static pressure drop (including losses in inlet scoop and outlet header), the heat transfer to the air, and the static pressure drop of the exhaust gas across the exchanger. Some additional data were obtained relative to each installation such as the temperatures of points on exhaust shroud and the total pressure at the air inlet scoop. The following temperature and pressure data were obtained:

Temperatures

1 Exhaust gas forward of the heat exchanger
2 Exhaust gas aft of the heat exchanger
3 Ambient air
4 Heated air out of the heat exchanger
5 Various points of the heat exchanger and exhaust shrouds, and the heat-exchanger air outlet header
6 Exhaust-stack wall at the locations of the forward and aft exhaust-gas thermocouples

Pressures

1 Static in the exhaust stack forward of the heat exchanger
2 Exhaust-gas static pressure drop across the heat exchanger
3 Total in the air inlet scoop
4 Static in the air inlet scoop
5 Static in the heated-air outlet ducting
6 Static at venturi meters used to obtain the air-flow rates

Unshielded thermocouples were used to indicate all temperatures except that of the ambient air, which was obtained with a glass-stem thermometer in a radiation shield mounted in the air stream. Chromel-alumel wire was used for the thermocouples in the exhaust-gas stream, and iron-constantan wire was used for all others. The types of thermocouples used are shown in figure 61. The temperatures were obtained with a portable potentiometer. The pressures were obtained with static or total tubes as shown in figure 61. The absolute value of the static pressure in the exhaust stack forward of the heat exchanger was indicated on a manifold-pressure gage. The exhaust-gas static pressure drop across the heat exchanger and all air pressures were indicated on water manometers. The air pressures were referred to the static pressure of the service airspeed head. The locations of the thermocouples and pressure tubes are shown on the installation drawings of each heat exchanger (figs. 24 to 44). The instrumentation of all heat exchangers was similar with respect to locations and types of thermocouples and pressure tubes used.

When the heat-exchanger tests were completed, a quadruple-shielded thermocouple, shown in figure 62, was installed in the exhaust stacks of engines 1 and 3 to provide an indication of the radiation error of the unshielded gas thermocouples. The shielded thermocouple was installed in the center of the the regular straight sections of exhaust stack which had been replaced by the heat exchangers. Thus, in nacelle 1, the shielded thermocouple was located approximately halfway between stations 2A and 2B (fig. 24), and in nacelle 3, approximately halfway between stations 2 and 2D (fig. 34). The section of straight exhaust stack was lagged with asbestos, approximately three-eighths inch thick, and the unshielded thermocouples used during the heat-exchanger tests were left in place in the unlagged portions of the exhaust system.

A single unshielded thermocouple (fig. 61) and a venturi meter were installed in the heated-air discharge ducts of the final heat-exchanger installations in nacelles 1 and 4. In the case of the final installation for nacelle 3, an unshielded thermocouple was installed in the duct between the exchanger outlet header and the discharge-valve assembly. The venturi meter, located between the exchanger in nacelle 3 and the heated-air discharge louver for the performance tests, was left in place.

Although during the preliminary tests of the final heat-exchanger installations the heated air was directed overboard only, a single unshielded thermocouple was located in the duct which directed the heated air to the wing outer panels of the installation in nacelles 1 and 4 for use during the service tests. Also, for the right wing, the quantity of air flow could be determined when the air was directed to the ice-prevention system by means of the venturi meter located near the outer panel joint (reference 2).

During the tests of the final heat-exchanger installations, instrumentation was provided in nacelle 3 to obtain the turbine-supercharger speed and angular position of the waste-gate butterfly valve. An indicating tachometer was connected to the turbine supercharger, and an NACA control-position recorder was attached to the waste-gate butterfly valve.

TESTS

Prior to flight tests, the engines were operated on the ground with the heat exchangers installed. All pressure and temperature data were recorded for the heat-exchanger installations at engine-power conditions of approximately 16 inches of mercury manifold pressure and 1200 rpm engine speed. The engines were also operated at high-power conditions of full throttle and full boost in order to investigate the maximum temperatures of the heated air and parts of the exhaust shroud under these severe conditions of low air-flow rate and high exhaust-gas-flow rate and temperature.

When the heat-exchanger installations were considered satisfactory, as determined by the ground testing, the flight tests were made to investigate the performance of the heat exchangers at various flight conditions. Pressure and temperature data were recorded for each heat exchanger during rated-power climbs and normal descents at various altitudes. Data were also recorded during cruising-power level flights for all of the heat exchangers at 16,000 feet pressure altitude; for heat exchangers 1, 2, and 3 at 25,000 feet pressure altitude; for heat exchangers 4, 5, 6, and 7 at 30,000 feet pressure altitude; and for heat exchangers 5, 6, and 7 at 34,600 feet pressure altitude. For each flight condition the engine power was repeated, as nearly as possible, for all heat exchangers tested. The heated-air temperatures and air-flow rates were obtained for the final installations of heat exchangers 3, 5, and 7 during rated-power climb and level-flight conditions similar to the performance tests in order that the final installations could be compared to the performance-test installations.

Night flights were conducted to observe the flaming of the exhaust gas and glowing of the exhaust stack and turbine supercharger for each exchanger-performance installation with the exception of exchanger 5. Visual observations were made from the ball turret of the test airplane, from an accompanying airplane, and from the ground. The observer in the test airplane was stationed in the ball turret and made observations during level flight at various engine-power conditions. The accompanying airplane, with two observers exclusive of the flight crew, was maneuvered about the B-17F airplane at a distance of approximately 300 feet. Observations of each heat-exchanger installation were made from several positions: from each side, directly below, and below and slightly aft. In addition to the above tests, the B-17F airplane was flown at altitudes of 300 and 500 feet over two observers stationed on the ground.

When the performance tests of the heat exchangers were completed and the quadruple-shielded thermocouples were installed in the exhaust stacks, temperature data were recorded for the unshielded and shielded thermocouples during rated-power climb and level-flight conditions similar to the conditions at which the heat exchangers were tested.

For the investigation of the effect of the heat-exchanger installation on the turbine-supercharger operation, tests were conducted at the same flight conditions with and without heat exchanger 7 installed in nacelle 3. Rated-power climbs were made to approximately 31,000 feet pressure altitude to investigate the critical altitude of the turbine supercharger for this power condition. The test climbs were made with full throttle under the operating conditions of constant manifold pressure, engine speed, and indicated airspeed. The manifold pressure was maintained constant by adjustment of the boost control. Level flights were conducted at 25,000 feet pressure altitude to determine the effect on the turbine speed and waste-gate-valve position of (1) varying engine speed (at full throttle and full boost) and (2) varying manifold pressure (at full throttle and constant engine speed). For part (1), the engine speed was changed by adjustment of the propeller pitch control and for part (2) the manifold pressure was changed by operating the boost control.

RESULTS

The data recorded during the performance tests of the seven heat exchangers are presented in tables I to VII, inclusive. The reference pressure, which was the static pressure of the service airspeed head, has been corrected to true ambient static pressure. The pressure correction applied was obtained from a calibration of the service airspeed head by means of a static head suspended beneath the airplane. The data obtained during the operation of the engines at high power on the ground and during take-off are not complete and do not represent a state of equilibrium. The length of time that the engines could be operated safely at this high power without overheating did not permit a state of equilibrium to be reached. The data for these conditions have been included because they are indicative of the maximum values which might be attained under these severe operating conditions. The ranges of altitude given in the tables for the climb and descent runs represent the change in altitude during the recording of the data.

The evaluation of the general performance characteristics of the seven heat exchangers is presented in tables VIII to XIV, inclusive, which were prepared from the data in tables I to VII, inclusive. The heated-air temperature given in these tables is the average value of the five-thermocouple survey located in the heated-air outlet duct. The air-temperature rise was determined from the ambient-air temperature and the average heated-air temperature. The rate of heat transferred was based upon the air-temperature rise, the air-flow rate, and the specific heat of the air at the arithmetic average of the ambient air and the heated-air temperatures.

The measured static pressure at the air inlet scoop was corrected for the difference in cross-sectional area between the air inlet scoop and the heated-air outlet duct. The difference between this corrected static pressure at the air inlet scoop and the static pressure measured at the heated-air outlet duct is presented in each table as the air-side static pressure drop. The exhaust-gas pressures were measured at points of equal cross-sectional area and, therefore, no area correction to the recorded pressure differences was necessary.

The data obtained for the tests conducted with the shielded thermocouples installed in the exhaust stacks of engines 1 and 3 indicated a difference in temperature between the shielded and unshielded thermocouples ranging from 120° to 160° F for the level-flight and descent test conditions, and from 60° to 80° F for the climb condition, with no consistency of the data within these ranges. The corrected exhaust-gas temperatures presented in tables VIII to XIV, inclusive, are the recorded values increased by 140° F for the level-flight and descent test conditions, and increased by 70° F for the climb condition. The values of the exhaust-gas-flow rate given in the tables were calculated from engine-performance data.

The results of the flame-suppression tests are given in table XV. No attempt was made to measure the intensity of the visually observed flame or glow because it was believed that whether or not the flame and glow were visible to the eye was a fundamental criterion of flame suppression. During all of the night flights conducted to observe exhaust flaming, heat exchangers were installed in nacelles 1, 3, and 4, and the glycol boilers of the service cabin-heating system were in nacelle 2; therefore, no indication of the intensity of the flaming or glowing was obtained for the regular exhaust system. The exhaust flaming, which was visible only from the ball turret of the test airplane, was a blue haze of low intensity. The type of fuel used in the engines may have an effect on the intensity of exhaust flaming; however, only aircraft engine fuel, grade 130, aromatic was used during the reported tests.

The heat exchangers were not tested for a sufficient length of time to provide conclusive information regarding the service life of the various units; however, each heat exchanger was visually inspected for indications of failure after the tests had been completed. A discoloration of the metal on all heat exchangers was observed to be more pronounced on the exhaust-gas side than on the air side. A slight roughness of the metal on the exhaust-gas side, especially noticeable in heat exchanger 1, was found at the forward end of the heat exchangers. In all cases, the amount of discoloration and roughness did not appear to exceed that of the regular exhaust system. Small cracks were observed at the forward end of heat exchangers 6 and 7 in the region where the flutes were joined together. Prior to the inspection, heat exchangers 1, 2, and 3 had been tested for approximately 21 hours, 4 for approximately 18 hours, 5 for approximately 11 hours, and 6 and 7 for about 29 hours.

The results of the preliminary testing of the final installations of heat exchangers 3, 5, and 7 are given in table XVI. Since the performance characteristics of the heat exchangers had been investigated, and these three final installations were specifically for service testing, complete temperature and pressure data were not obtained.

The effect of heat exchanger 7 installation in nacelle 3 on the turbine speed and waste-gate-valve position for the three test conditions investigated is shown in figures 63 to 65 inclusive.

Figure 63 presents the results of the rated-power climb tests, and figures 64 and 65 present the results of the level-flight investigations.

DISCUSSION

The possibility of determining a single index which can be used for comparing all heat exchangers has been the subject of much discussion and research. The large number of factors involved (heat output, temperature rise, resistance to exhaust-gas-and-air flow, and exchanger weight and volume) makes the selection of the optimum exchanger very dependent upon the particular application. This problem of establishing a "coefficient of performance" for heat exchangers was also encountered during the investigations of reference 1, in which several exchangers of different design and anticipated output were tested. A reasonably satisfactory basis for the comparison of different exchanger designs exists, however, when all the exchangers are intended for the same installation, as in the case of the reported investigation. Accordingly, the design requirements of the heat-exchanger installations for a typical four-engine bomber airplane thermal ice-prevention and cabin-heating systems have been chosen as the basis for the comparison of the seven heat exchangers.

The design requirements are given for the critical conditions of the outboard- and inboard-nacelle heat-exchanger installations. The outboard-nacelle installations, to be used for the wing ice-prevention system only, were considered to be critical for 18,000 feet pressure altitude at maximum range cruising-flight conditions. The inboard-nacelle installations, to be used for the empennage ice-prevention and cabin-heating systems, were considered to be critical at 35,000 feet pressure altitude for cabin-heating use during maximum range cruising-flight conditions. Unfortunately, the test conditions were not identical to the design specifications because the specifications were not available until the investigations were almost completed, and because the factors involved in flights at high altitudes restricted operations at 35,000 feet. The test conditions, nevertheless, closely approximated the design assumptions in most cases and, in general, provided data from which the relative ability of the various exchangers to satisfy the design requirements could be estimated.

The design requirements and the performance data to be compared with those requirements are presented in table XVII. Although exchanger 2 was installed in nacelle 3, it was not tested at 35,000 feet (design requirement for the inboard exchangers) and hence has been listed with the outboard exchangers in the table. The exchanger was of comparable size with those tested in the outboard nacelles and can reasonably be included with them for the purposes of discussion. All three of the exchangers for which test data were obtained at 34,600 feet have been grouped together for comparison with the inboard-nacelle requirements even though two of these exchangers were designed for the outboard nacelles.

The desired values of the total pressure drop for the exhaust-gas and air sides of the heat-exchanger installations were specified in the design requirements. However, the total pressure drops were not obtained during the testing because of the difficulties and complications associated with the instrumentation necessary to determine correctly the total pressure profiles across the heated-air outlet duct and the exhaust stack. On the exhaust-gas side there was little space available for the location of pressure tubes aft of the exchangers and between the heat exchangers and the engine-exhaust collector. (See the figures of the heat-exchanger installations.) An indication of the static pressure drop across the gas side of the exchangers was obtained and may be used in comparing the various exchangers but should not be compared with the design total pressure drops. With regard to the air side of the heat exchangers, the velocity distribution across the air-inlet-scoop entrances was sufficiently constant to allow the total pressure to be evaluated from a three-tube total-pressure survey.

In the heated-air outlet only the static pressure, which has essentially a constant value at any duct section, was measured. A reasonable approximation of the total pressure in the air outlet, however, can be obtained by adding a calculated value of the dynamic pressure in the outlet to the measured static pressure. The flow in the heated-air outlet ducting was assumed to be turbulent and the relationship used to calculate the dynamic pressure was $q = \frac{1}{2}\rho V^2$; where q is the dynamic pressure, ρ is the density of the air, and V is the average air velocity in the duct. The calculated values of total pressure in the air outlet duct were subtracted from the values measured at the air inlet to provide the total pressure drops presented in table XVII.

A consideration of the rate of heat transfer of heat exchangers 1 to 6, inclusive, indicates that only exchanger 5 exceeded the design requirement for the outboard-nacelle installation at 18,000 feet pressure altitude. However, the test indicated airspeed was below the design value and it is probable that the rate of heat transfer of exchangers 1, 2, 3, 4, and 6 would satisfy the requirement if tested at design airspeed conditions. Attention is directed to the fact that, although the design rate of heat transfer may be realized, the heat-exchanger performance may not be satisfactory unless the air-flow rate and temperature rise, which determine the rate of heat transfer, also meet the design requirements. For heat exchangers 1 to 6, inclusive, the air-flow rates were below the design values, and the air-temperature rises, except for exchanger 4, exceeded the design requirements. The heated-air-temperature rise produced by exchanger 4 was within the range specified in the design requirements, but the air-flow rate was low. This general condition of low flow rate and high temperature rise indicates that the pressure drop across the exchangers was high, which is verified by the values of total pressure drop given in table XVII. Of the six exchangers compared with the design requirements for the outboard nacelles, exchanger 5 most nearly approached the design pressure drop and air-flow rate. The combination of low air-flow rate and low total pressure drop presented for exchanger 2 indicates that the heated-air outlet ducting contributed more to the over-all pressure loss in the inboard-nacelle than in the case of the outboard-nacelle installations. A total pressure drop across the exchanger 2 installation equal to the allowable design requirement would probably have resulted in an air-flow rate, temperature rise, and rate of heat transfer close to the design specifications.

In the interpretation of the air-side total pressure drops for the heat exchangers, it is important to realize that the values given in table XVII include the pressure drop through the air inlet scoop, the heat exchanger proper, and the air outlet header. It is possible, however, to obtain a relative indication of the pressure loss to be attributed to the exchanger itself by a comparison of the test data for similar installations, such as those of exchangers 1, 3, 4, and 5. On this basis it may be seen that exchanger 1 installation had the highest pressure drop at the lowest flow rate, and since the installation of this exchanger was similar to those of exchangers 3, 4, and 5, it is probable that the pressure drop across the exchanger proper was approximately twice that for exchanger 5. Exchanger 6, although tested in the outboard nacelles, has not been considered in this comparison because this was a cross-flow heat exchanger and required a different type of installation.

An indication of the effect of air inlet scoop, heat-exchanger shroud, and outlet design on the performance of an exchanger installation is illustrated by a comparison of the data for exchanger 3 installed for performance tests and for service tests. (See tables X and XVI.) The final installation of exchanger 3 was designed to have a lower air-side pressure drop than the test installation. Although the final installation pressure drop was not measured, a reduction was apparently achieved as evidenced by the increase in the air-flow rate and the decrease in air-temperature rise.

A comparison of the performance data for exchangers 5, 6, and 7 with the design requirements at 35,000 feet pressure altitude indicates that the rate of heat transfer of the exchangers was below the design value. Although exchanger 7 was the only unit specifically designed for use in the inboard nacelles, the test data show that the rate of heat transfer for exchanger 5 almost equaled that of exchanger 7. Although the test indicated airspeed was below the design value and the exchanger rates of heat transfer would increase as the design airspeed is approached, it is questionable whether the required rate of heat exchange could be achieved by either

5 or 7 under design conditions. The performance data indicate that for exchangers 5 and 7, the air-flow rate and air-temperature rise, which determine the rate of heat transfer and must meet design requirements if the performance of the ice-prevention or cabin-heating system is to be satisfactory, were, respectively, below and above design values. This reported performance of the installations indicates a high air-side pressure drop which is substantiated by the data presented in table XVII. The high air-temperature rise experienced with the installation of exchanger 7 in nacelle 3 was the reason for the adaptation of the cold-air tempering system already described under the discussion of final or service-test installations. The effect of this tempering system in reducing the temperature of the heated air directed to the empennage is shown to be satisfactory by a comparison of data in tables XIV and XVI.

A comparison of the performance data recorded for each exchanger at different altitudes indicates that, in general, the air-flow rate decreased and the air-temperature rise increased as the altitude was increased for similar airspeed and engine-power conditions. The recorded decrease in air-flow rate had a greater effect on the rate of heat transfer than did the increase in air-temperature rise, resulting in a decrease in the rate of heat transfer. These results indicate that the variation of heat-exchanger performance with changes in altitude is an important consideration in the design of such installations. The application of exhaust-gas heat exchangers to future engine installations in which satisfactory exchanger performance is required over a large range of airplane and engine operating conditions will probably lead to the development of air-tempering systems and exhaust-gas bypass devices.

The results of the flame-suppression tests indicated that the intensity of the exhaust flaming was not sufficient to be visible at an estimated distance of 300 feet, but that the glow of portions of the exhaust system and the turbine supercharger was visible. Exhaust flaming, as a blue haze, observed from the ball turret of the test airplane, indicated that flaming did exist but was of low intensity. In the evaluation of the results of the flame-suppression investigation, the background conditions should be considered. For the reported tests, it was observed that the moon was not visible when heat exchangers 1, 2, and 3 were tested, but was visible near the end of the flights when heat exchangers 4, 6, and 7 were installed. During all of the tests, ground lights were visible but, when observations were being made, the airplane was maneuvered so that the source of light was not in the background.

The results of the tests to investigate the operation of the turbine supercharger with and without exchanger 7 installed indicate that in a rated engine-power climb, the speed (and, therefore, critical altitude) of the supercharger was not affected by the exchanger installation (fig. 63). However, it was found that the exchanger installation necessitated a greater closure of the waste-gate valve in order to maintain the manifold pressure at the rated-power value. The data in figure 65 indicate that a movement of the waste-gate valve from two-thirds closed to almost fully closed was required to attain the same manifold pressure in level flight with the exchanger installed as that obtained with no exchanger. The limited scope of the supercharger investigations precludes the presentation of definite statements regarding the effects of heat-exchanger installations on turbine-supercharger performance, and the data presented in figures 63, 64 and 65 should be interpreted with reservation.

The total time that the heat exchangers were tested was not sufficient to provide a basis for conclusions on the service life of the units. The discoloration which was observed when the heat exchangers were inspected did not appear to be excessive. The location of the small cracks observed on heat exchangers 6 and 7 at the forward end where the flutes were joined together indicated that failure was probably due to the method of fabrication of the heat exchangers. The cracks were in the region where a considerable amount of forming and welding was required in the fabrication, and the method of joining the flutes appeared to cause a concentration of stress at this point. It was also observed that the discoloration of the metal of exchangers 6 and 7 was most pronounced in the region where the cracks were located. The discoloration probably indicates that the distribution of air was not satisfactory to provide sufficient cooling of this area.

In the installation of exchangers 6 and 7, the clamp connections which joined the heat exchanger to the exhaust stack were located within the air shrouding and, therefore, any leakage of exhaust gas at these joints would enter the air stream. Exhaust-gas leakage at the clamp connections of exchanger 7 was evidenced by discolorations of the exhaust shroud in the vicinity of the clamps. If a heat-exchanger installation of this type were to be used for cabin heating, a secondary exchanger would be necessary in order to avoid the danger of introducing carbon monoxide into the airplane cabin. Installations similar to the cross-flow type tested are not subject to contamination of the heated air by exhaust-gas leakage at the attachment clamps because these connections are located outside the air passages; however, a secondary exchanger may be employed as a precautionary measure in the event of a minor failure of the exhaust-gas-to-air heat exchanger.

CONCLUDING REMARKS

The design requirements of heat exchanger installations for a typical four-engine bomber airplane are used as a basis for comparing the performance of the heat exchangers tested. The results indicated that the design rate of heat transfer for the outboard nacelle heat-exchanger installations would probably be provided by all the heat exchangers tested in those nacelles. It is questionable if any of the heat exchangers tested in the inboard nacelles would provide the rate of heat transfer specified for those nacelles. For all the heat exchangers tested, it was found that the air-side pressure drop across the exchangers was high and resulted in low air-flow rates and in most cases high air-temperature rises.

The flame-suppression tests results showed that the glowing of the exhaust stacks and turbine-supercharger parts was more visible than the exhaust gas flaming.

The limited data obtained on the effect of a heat-exchanger installation on the operation of a turbine supercharger indicated that the critical altitude of the supercharger for rated-engine-power conditions was not affected by the heat-exchanger installation. These data also show that, for a given engine manifold pressure, greater closure of the waste-gate butterfly valve was required with the exchanger installed than without the exchanger installed.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif., April 19, 1944.

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2. Jones, Alun R., and Rodert, Lewis A.: Development of Thermal Ice-Prevention Equipment for the B-17F Airplane NACA ARR No. 3H24, 1943.

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TABLE I.- DATA RECORDED FOR EXCHANGER 1 TESTED IN NACELLE 1 OF THE B-17F AIRPLANE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Run number	1	2	3	4	5	6	7	8	9	10	11
Flight conditions	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Level	Descent	Descent	Descent
Manifold pressure, in. Hg:											
No. 1 engine - - - - - - - - - - -	16	44	37	36.5	38.5	26	37	26.3	20	19	20
No. 2 engine - - - - - - - - - - -	16	44	37	38.5	38.5	28	37	26	20	19	20
No. 3 engine - - - - - - - - - - -	16	44	38.3	38.5	58.3	23	37	27	19.5	19	20
No. 4 engine - - - - - - - - - - -	18	44	38.3	38.3	38.3	28	37	27.5	19.3	19	20
Engine speed, rpm:											
No. 1 engine - - - - - - - - - - -	1150	2500	2300	2300	2300	1800	2500	1900	1800	1800	1600
No. 2 engine - - - - - - - - - - -	1150	2500	2300	2300	2300	1800	2300	1900	1800	1800	1800
No. 3 engine - - - - - - - - - - -	1150	2500	2300	2300	2300	1823	2300	2040	1800	1800	1800
No. 4 engine - - - - - - - - - - -	1200	2500	2300	2300	2300	1823	2300	1900	1600	1800	1800
Indicated airspeed, mph - - - - -	----	----	154	133	155	128	133	129	153	148	160
Pressure altitude, ft - - - - - -	Sea level	Sea level	3,000 7,000	8,000 12,000	12,400 16,400	18,000	20,300 24,300	24,800	24,500 21,500	17,200 14,200	8,000 3,000
Mixture setting, automatic rich or lean - - - - -	A.R.	A.R.	A.R.	A.R.	A.R.	A.L.	A.R.	A.L.	A.L.	A.L.	A.L.
Temperatures, °F:											
Ambient air - - - - - - - - - - -	66	62	57	48	17	14	12	-9	-2	18	53
T_{39}, exhaust gas in - - - - - -	----	----	1554	1384	1546	1626	1376	1680	1555	1499	1596
T_{40}, exhaust stack wall at T_{39} -	527	----	876	906	910	1022	1114	1110	1007	883	779
T_{41}, exhaust stack wall at T_{39} -	337	----	990	1034	1032	1072	1097	1158	953	906	815
T_{42}, exhaust stack wall at T_{39} -	601	----	----	----	----	1149	1145	1203	997	963	866
T_{43}, exhaust gas out - - - - - -	950	----	1462	1480	1475	1522	----	----	----	----	----
T_{45}, exhaust stack wall at T_{43} -	281	----	----	----	----	642	704	694	----	526	393
T_{46}, exhaust stack wall at T_{43} -	440	----	825	644	850	804	900	898	799	657	565
T_{49}, air out (survey) - - - - -	307	464	476	495	485	479	536	320	440	370	332
T_{50}, air out (survey) - - - - -	517	----	469	495	484	482	544	525	428	555	307
T_{51}, air out (survey) - - - - -	507	----	436	474	472	457	520	486	598	337	290
T_{52}, air out (survey) - - - - -	294	----	440	452	450	434	495	450	373	320	280
T_{53}, air out (survey) - - - - -	279	----	404	416	414	592	464	399	340	294	264
T_{54}, exchanger outlet - - - - -	243	----	426	437	437	424	498	438	353	283	251
T_{55}, exchanger shroud - - - - -	138	----	----	----	----	200	260	208	213	127	120
T_{56}, exhaust shroud, forward - -	130	----	180	146	137	187	233	194	310	158	130
T_{57}, exhaust shroud, aft - - - -	131	254	276	309	523	323	440	400	237	160	127
Pressures:											
[a] P_{21}, exhaust gas in, static - -	31	36.3	55.9	28.4	27	20	25.5	18.4	13	17	----
[b] $P_{21}-P_{22}$, exhaust gas static ΔP_g	----	3.5	2.9	5.2	3.3	----	----	----	----	----	----
[c] P_{23}, air in, static - - - - - -	2.5	2.5	13.3	15.5	12.8	10.3	12	16	12.3	12.3	14
[c] P_{24}, air in total, top - - - - -	2.5	----	13.3	15.3	12.9	10.5	11.9	10.0	12.7	13.3	14.4
[c] P_{25}, air in total, center - - -	2.5	----	13.7	15.4	15.0	10.6	12.2	10.3	12.7	15.7	14.4
[c] P_{26}, air in total, bottom - - -	2.3	----	13.5	12.3	15.0	11.0	12.0	10.4	12.9	13.3	----
[c] P_{27}, air out, static - - - - - -	1.3	----	-0.4	-0.6	-0.8	-1.2	-1	-1	-1.8	-1.3	-1

[a] Inches of mercury, absolute.
[b] Inches of water.
[c] Inches of water, referred to ambient static pressure.

TABLE II.- DATA RECORDED FOR EXCHANGER 2 TESTED
IN NACELLE 3 OF THE B-17F AIRPLANE

Run number	1	2	3	4	5	6	7	8	9	10	11
Flight condition	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Level	Descent	Descent	Descent
Manifold pressure, in. Hg:											
No. 1 engine - - - - - - - - - - -	18	44	37	38	38	28	37	28.5	20	22	20
No. 2 engine - - - - - - - - - - -	16	44	37	38	38	28	37	28	19.3	21	20
No. 3 engine - - - - - - - - - - -	16	44	37	58	39	25	37	27	19.3	21	20
No. 4 engine - - - - - - - - - - -	16	44	57	36	38	28	37	27.5	19.3	18	20
Engine speed, rpm:											
No. 1 engine - - - - - - - - - - -	1130	2500	2500	2300	2500	1800	2300	1900	1800	1800	1800
No. 2 engine - - - - - - - - - - -	1160	2800	2300	2300	2300	1800	2300	1900	1800	1800	1800
No. 3 engine - - - - - - - - - - -	1150	2500	2300	2300	2300	1825	2300	2040	1800	1800	1800
No. 4 engine - - - - - - - - - - -	1200	2500	2300	2300	2500	1825	2500	1900	1800	1800	1800
Corrected indicated airspeed, mph - - - - -	——	106	133	133	133	128	153	129	138	158	165
Pressure altitude, ft - - - - -	Sea level	Sea level	3,300 7,500	6,000 12,000	12,000 16,000	18,300	20,800 24,800	25,000	24,500 21,500	21,000 18,000	7,000 4,000
Mixture setting, automatic rich or lean - - - - -	A.R.	A.R.	A.R.	A.R.	A.R.	A.L.	A.S.	A.L.	A.L.	A.L.	A.L.
Temperatures, °F:											
Ambient air - - - - - - - - - - -	68	62	59	50	56	10	12	-9	-2	3	56
T_{20}, exhaust gas in - - - - - - -	1072	——	1320	1329	1486	1506	1500	1628	1478	1290	1190
T_{21}, exhaust stack wall at T_{20} -	643	——	753	780	830	889	900	997	1111	806	670
T_{22}, exhaust stack wall at T_{20} -	694	——	1044	1042	1077	——	——	1200	——	945	787
T_{23}, exhaust stack wall at T_{20} -	——	——	1031	——	1064	——	——	——	——	——	——
T_{24}, exhaust gas out - - - - - -	911	——	922	892	1319	1140	1558	750	1250	1249	1152
T_{25}, exhaust stack wall at T_{24} -	308	——	545	533	570	447	595	607	390	406	319
T_{26}, exhaust stack wall at T_{24} -	381	——	498	515	524	597	520	549	534	350	265
T_{27}, exhaust stack wall at T_{24} -	480	——	631	552	864	682	920	529	580	310	530
T_{30}, air out (survey) - - - - -	502	——	278	426	432	572	480	479	568	330	275
T_{31}, air out (survey) - - - - -	360	402	438	442	448	398	498	490	590	338	300
T_{32}, air out (survey) - - - - -	313	——	440	445	454	398	504	490	387	368	295
T_{33}, air out (survey) - - - - -	295	——	424	433	439	382	490	473	370	348	288
T_{34}, air out (survey) - - - - -	274	——	405	410	418	348	468	443	540	315	269
T_{35}, heater outlet, skin - - - -	380	——	435	400	402	400	504	485	398	355	578
T_{36}, heater shroud, skin - - - -	131	——	147	138	131	140	155	177	155	131	135
T_{37}, exhaust shroud, forward - -	167	259	290	282	284	213	524	430	216	178	169
T_{38}, exhaust shroud, aft - - - -	131	——	153	155	149	123	162	190	148	169	178
Pressures:											
[1] P_{11}, exhaust gas in, static - -	31	57.5	32	30	29	20	27.5	20.1	15.5	——	——
[2] $P_{11}-P_{12}$, exhaust gas, ΔP_E, static	——	15	26.5	28	29	11.3	33	17	10.5	——	——
[3] P_{14}, air in, total, top - - - -	2.1	——	13.9	12.5	13.2	11.2	12.3	10.8	11.6	14.3	15.2
[3] P_{15}, air in, total, center - - -	2.0	——	15.7	12.1	15.0	11.8	13.0	10.8	11.5	14.0	15.2
[3] P_{16}, air in, total, bottom - - -	2.0	——	13.7	13.2	13.0	11.8	12.9	10.8	11.5	14.0	15.2
[3] P_{13}, air in, static - - - - - -	1.5	——	13.3	13	12.8	11.3	12.3	10.9	10.8	13.5	14.5
[3] P_{17}, air out, static - - - - - -	0.8	——	6	8	5	5	4.3	4.8	4.8	5.8	6

[1] Inches of mercury, absolute.
[2] Inches of water.
[3] Inches of water, referred to ambient static pressure.

TABLE III.- DATA RECORDED FOR EXCHANGER 3 TESTED
IN NACELLE 4 OF THE B-17F AIRPLANE

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Run number	1	2	3	4	5	6	7	8	9	10	11
Flight conditions	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Level	Descent	Descent	Descent
Manifold pressure, in. Hg:											
No. 1 engine - - - - - - - - - -	16	44	38.5	38	38	26	37	26.5	20	19.6	19
No. 2 engine - - - - - - - - - -	16	44	37.5	38	38	26	37	26	20	19.6	19
No. 3 engine - - - - - - - - - -	16	44	38	36	38	26	37	27	19.5	19.6	19
No. 4 engine - - - - - - - - - -	16	44	39	38	38	26	37	27.6	19.5	19.6	19
Engine speed, rpm:											
No. 1 engine - - - - - - - - - -	1150	2500	2300	2300	2300	1800	2300	1900	1600	1800	1800
No. 2 engine - - - - - - - - - -	1150	2600	2300	2300	2300	1800	2300	1900	1800	1600	1800
No. 3 engine - - - - - - - - - -	1150	2500	2600	2300	2300	1826	2300	2040	1800	1800	1800
No. 4 engine - - - - - - - - - -	1200	2500	2300	2300	2300	1826	2300	1900	1800	1800	1800
Indicated airspeed, mph - - - -	------	106	136	133	135	126	134	129	143	150	156
Pressure altitude, ft - - - - -	Sea level	Sea level	3,200 7,200	8,400 12,400	13,300 17,300	18,000	20,300 24,300	25,100	24,700 21,700	20,000 17,000	7,000 4,000
Mixture setting, automatic rich or lean - - - -	A.R.	A.R.	A.R.	A.R.	A.R.	A.L.	A.R.	A.L.	A.L.	A.L.	A.L.
Temperatures, °F:											
Ambient air - - - - - - - - - -	66	82	54	59	32	16	16	-11	-6	16	44
T_1, exhaust gas in - - - - - - -	1114	------	1500	1500	1540	1582	1572	1625	1500	1514	1441
T_2, exhaust stack wall at T_1 -	730	------	1016	1056	1064	1126	1145	1220	1020	945	840
T_3, exhaust stack wall at T_1 -	660	------	832	856	884	1063	948	1080	978	958	836
T_5, exhaust gas out - - - - -	577	------	1374	1390	1398	1376	1444	------	1290	1260	1166
T_6, exhaust stack wall at T_5 -	367	------	842	684	676	779	920	853	856	604	448
T_7, exhaust stack wall at T_5 -	408	------	706	741	780	717	836	768	626	592	484
T_8, exhaust stack wall at T_5 -	443	------	832	884	922	657	980	947	746	660	617
T_{11}, air out } Survey - - - - - - - -	284	------	580	388	402	345	442	386	299	290	265
T_{12}, air out } Survey - - - - - - - -	280	------	580	388	405	346	442	381	296	290	266
T_{13}, air out } Survey - - - -	626	------	411	417	440	661	478	416	366	624	268
T_{14}, air out } Survey - - - - - - - -	291	------	366	393	420	349	454	398	307	295	246
T_{15}, air out } Survey - - - - - - - -	632	440	436	448	461	418	498	440	370	654	293
T_{16}, heater outlet, skin - - -	332	------	432	442	469	416	496	457	365	660	300
T_{17}, heater shroud, skin - - -	672	------	985	1000	1050	976	1111	1001	650	606	677
T_{18}, exhaust shroud, forward -	167	------	210	220	272	345	350	342	257	226	173
T_{19}, exhaust shroud, aft - - -	168	234	276	608	684	610	------	434	------	------	------
Pressures:											
[1] P_1, exhaust gas in, static - -	61	36.5	32.5	30.5	29.5	21	------	20.3	16	14.8	26
[2] P_1-P_2, gas static, ΔP_2 - - -	------	8.5	------	------	------	3.5	------	12	7	1.5	4.5
[2] P_3, air in static - - - - - - -	1.5	------	11.5	11.3	11.2	9.5	10.6	9	9.5	10.5	11
[3] P_4, air in total, top - - - -	2.1	------	13.8	12.7	13.0	11.6	12.0	10.2	11.3	12.4	13.7
[3] P_5, air in total, center - -	2.1	------	13.7	13.0	13.2	11.6	12.0	10.5	11.2	12.4	13.7
[3] P_6, air in total, bottom - -	2.2	------	13.7	13.0	13.2	11.5	12.0	10.4	10.5	12.7	14.0
[3] P_7, air out static - - - -	1.0	------	1.5	1.2	0.8	0.4	0.4	0.6	0.4	0.6	1.3

[1]Inches of mercury, absolute.
[2]Inches of water.
[3]Inches of water, referred to ambient static pressure.

TABLE IV.- DATA RECORDED FOR EXCHANGER 4 TESTED IN NACELLE 4 OF THE B-17F AIRPLANE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Run number	1	2	3	4	5	6	7	8	9	10	11	12	13
Flight conditions	Ground	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Climb	Level	Descent	Descent	Descent
Manifold pressure, in. Hg:													
No. 1 engine	----	----	44.0	39.0	38.0	37.3	27.0	36.6	37.0	27.0	14.0	19.0	18.2
No. 2 engine	----	----	44.0	38.0	38.0	37.3	27.9	37.2	37.0	27.0	17.5	19.8	19.0
No. 3 engine	----	----	40.0	39.0	38.0	37.3	27.2	37.1	36.8	27.0	18.0	18.8	19.6
No. 4 engine	16.0	45.5	44.0	39.0	38.0	37.5	27.2	37.0	37.0	27.0	21.8	18.0	19.8
Engine speed, rpm:													
No. 1 engine	----	----	2430	2300	2300	2300	1750	2300	2300	2100	1830	1825	1825
No. 2 engine	----	----	2500	2300	2300	2300	1770	2300	2300	2100	1800	1810	1810
No. 3 engine	----	----	2500	2300	2300	2300	1600	2300	2300	2100	1850	1840	1840
No. 4 engine	1225	2425	2500	2300	2300	2300	1600	2300	2300	2100	1820	1825	1820
Indicated airspeed, mph:	----	----	116	133	133	133	134	138	133	137	133	140	160
Pressure altitude, ft	Sea level	Sea level	Sea level	5,000 9,000	10,000 14,000	13,800 17,800	18,200	23,000 27,000	28,000 32,000	30,000	28,000 23,000	20,000 17,000	5,800 2,800
Mixture setting, automatic rich or lean	A.R.	A.R.	A.R.	A.R.	A.R.	A.R.	A.L.	A.R.	A.R.	A.L.	A.L.	A.L.	A.L.
Temperatures, °F:													
Ambient air	70	70	----	68	59	48	28	0	-24	-26	-18	17	68
T_1, exhaust gas in	1160	1120	----	1587	1800	1610	1603	1650	1678	----	1530	1470	1649
T_2, exhaust stack wall	722	----	----	1208	1120	1144	1130	1078	1200	1306	1074	957	870
T_3, exhaust stack wall	720	----	----	1200	1200	1205	1108	1230	1248	1218	1019	806	790
T_4, exhaust stack wall	574	----	----	887	1005	1027	1070	1082	1232	1274	1090	1002	912
T_5, exhaust gas out	909	----	----	1451	1454	1468	1430	1518	1546	1348	1337	1282	1214
T_6, exhaust stack wall	336	----	----	936	864	1005	893	1055	1096	1038	852	590	----
T_7, exhaust stack wall	392	----	----	725	751	777	687	828	878	868	644	318	438
T_8, exhaust stack wall	450	----	----	887	810	943	833	1013	1052	1035	794	638	530
T_{11}, air out (survey)	274	420	----	350	347	350	315	372	371	344	249	237	230
T_{12}, air out (survey)	278	448	----	360	364	388	327	384	384	331	262	248	240
T_{13}, air out (survey)	340	310	435	440	423	423	380	422	413	378	305	304	295
T_{14}, air out (survey)	307	484	403	410	410	413	353	408	418	378	295	288	269
T_{15}, air out (survey)	332	482	400	373	383	387	363	400	418	410	296	287	262
T_{16}, heater outlet skin	277	----	----	295	308	312	262	314	318	278	200	197	220
T_{17}, heater shroud skin	143	----	----	230	259	272	239	252	249	233	177	147	148
T_{18}, exhaust shroud forward	119	----	142	173	202	227	207	227	225	230	200	148	155
T_{19}, exhaust shroud aft	124	----	166	196	262	315	241	406	471	272	165	98	116
Pressures:													
[1]P_1, gas in static	30.8	35.2	36	29.7	28.0	27.5	20.7	28.7	26.3	19.1	16.0	15.0	25.0
[2]P_1-P_2, gas static, ΔP_g	0.4	10.5	10	8.0	8.1	8.8	3.0	6.8	8.0	6.1	2.8	2.3	0.5
[3]P_3, air in static	2.1	7.5	----	11.9	12.0	11.4	10.0	10.3	10.1	10.3	9.3	9.3	12.3
[3]P_4, air in total, top	2.4	----	----	13.0	12.5	12.3	11.0	11.7	11.5	11.0	10.3	10.5	14.5
[3]P_5, air in total, center	2.4	----	----	13.2	12.3	12.5	10.8	11.7	11.3	10.8	10.1	10.5	14.5
[3]P_6, air in total, bottom	2.3	----	----	13.9	13.2	13.0	11.0	11.7	11.5	11.0	10.1	10.6	14.7
[3]P_7, air out static	0.9	2.3	----	2.3	2.3	2.0	1.5	1.5	1.3	0.9	1.0	1.4	2.5

[1]Inches of mercury, absolute.
[2]Inches of water.
[3]Inches of water, referred to ambient static pressure.

TABLE V.- DATA RECORDED FOR EXCHANGER 8 TESTED
IN NACELLE 4 OF THE B-17F AIRPLANE

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Run number	1	2	3	4	5	6	7	8	9	10	11	12	13
Flight conditions	Ground	Ground	Climb	Climb	Climb	Level	Climb	Climb	Level	Level	Descent	Descent	Descent
Manifold pressure, in. Hg:													
No. 1 engine - - - - - - - - - - -	18	------	38	38.5	37.5	27.5	37.5	37	30	25	13	17.5	18.5
No. 2 engine - - - - - - - - - - -	15	------	32.5	38	37.5	27.5	37.5	37	30	30	17	18.5	18.5
No. 3 engine - - - - - - - - - - -	15	------	37	38	37.5	27.5	37	37	30	30.5	18.5	18	18.5
No. 4 engine - - - - - - - - - - -	15	45	38.5	38	37.5	27.5	37	37	30	26	19.5	17.5	18.5
Engine speed, rpm:													
No. 1 engine - - - - - - - - - - -	1210	------	2300	2300	2300	1900	2300	2300	2200	2050	-------	-------	1800
No. 2 engine - - - - - - - - - - -	1250	------	2300	2300	2300	1900	2300	2300	2200	2200	1800	1800	1800
No. 3 engine - - - - - - - - - - -	1350	------	2300	2300	2300	1900	2300	2300	2200	2200	1800	1800	1800
No. 4 engine - - - - - - - - - - -	1275	2450	2300	2300	2300	1900	2300	2300	2200	2200	1800	1800	1500
Indicated airspeed, mph - - - - -	------	------	134	135	135	135	131	130	143	115	148	148	148
Pressure altitude, ft - - - - - -	Sea level	Sea level	3500 6500	8,500 11,500	13,500 16,500	18,100	23,500 28,500	28,500 31,500	30,000	34,600	26,500 23,500	19,500 18,500	6500 3500
Mixture setting, automatic rich or lean - - - - -	A.R.	A.R.	A.R.	A.R.	A.R.	A.L.	A.R.	A.R.	A.R.	A.R.	A.L.	A.L.	A.L.
Temperatures, °F:													
Ambient air - - - - - - - - - - -	66	66	72	59	41	23	9	-13	-19	-40	-4	23	66
T_1, exhaust gas in - - - - - - - -	1213	1811	1548	1588	1598	1825	1601	1627	1649	------	-------	-------	-------
T_3, exhaust stack wall - - - - -	838	------	------	------	-----	-----	-----	------	-----	------	-------	-------	-------
T_4, exhaust stack wall - - - - -	716	------	957	1012	996	1185	1061	1120	1199	1200	1061	1005	941
T_5, exhaust gas out - - - - - -	------	------	1461	1469	1473	1442	1499	1587	1514	1593	1311	1253	1226
T_8, exhaust stack wall - - - - -	411	------	889	900	903	656	960	1008	951	1027	741	634	550
T_7, exhaust stack wall - - - - -	454	------	767	796	818	-----	903	955	951	951	696	588	527
T_5, exhaust stack wall - - - - -	459	------	764	------	-----	765	-----	------	-----	------	-------	-------	-------
T_{11}, air out (Survey) - - - - - - -	299	------	350	364	378	315	416	442	374	498	262	229	222
T_{12}, air out (Survey) - - - - - - -	325	------	380	396	408	349	458	484	412	550	291	252	243
T_{13}, air out (Survey) - - -	339	------	------	------	-----	-----	-----	------	-----	------	-------	-------	-------
T_{14}, air out (Survey) - - - - - - -	355	496	422	435	448	392	500	534	461	506	334	255	271
T_{15}, air out (Survey) - - - - - - -	392	------	448	455	457	444	528	566	508	811	351	340	317
T_{16}, heater outlet, skin - - - -	211	------	298	306	309	282	358	432	370	508	232	196	181
T_{17}, heater shroud, skin - - - -	176	------	240	236	240	228	259	288	282	377	212	182	177
T_{15}, exhaust shroud, forward - -	155	------	165	159	152	225	172	192	309	350	268	213	205
T_{19}, exhaust shroud, aft - - - -	157	------	158	152	152	190	186	216	234	272	154	148	174
Pressures:													
[1]P_1, gas in, static - - - - - - -	30.5	------	30.8	28.0	27.0	20.2	27.0	27.2	21.5	------	12.0	25.0	24.5
[2]P_2-P_1, exhaust gas ΔP_E - - - -	0.4	5.8	3.8	4.5	4.8	2.4	4.5	5.4	4.5	------	-------	-------	0.0
[3]P_3, air in, static, center - - -	2.1	------	13.5	13.0	12.1	11.8	11.3	11.0	11.8	8.1	11.5	11.8	11.9
[3]P_4, air in, total, top - - - - -	2.1	------	13.0	12.7	12.2	11.2	11.0	10.8	12.2	7.9	11.7	12.0	12.4
[3]P_5, air in, total, center - - -	2.1	------	13.2	12.9	12.4	11.7	11.2	11.0	12.7	7.9	11.7	12.0	12.5
[3]P_5, air in, total, bottom - - -	2.0	------	13.0	13.0	12.7	11.7	10.8	10.3	12.7	7.8	11.7	11.7	12.2
[3]P_7, air out, static - - - - - -	0.8	------	1.9	1.8	1.3	0.9	1.1	1.1	0.9	0.1	0.8	1.1	1.1

[1]Inches of water, absolute.
[2]Inches of water.
[3]Inches of water referred to ambient static pressure.

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TABLE VI.- DATA RECORDED FOR EXCHANGER 5 TESTED IN NACELLE 1 OF THE B-17F AIRPLANE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Run number	1	2	3	4	5	5	7	8	9	10	11	12	13
Flight conditions	Ground	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Climb	Level	Level	Descent	Descent
Manifold pressure, in. Hg:													
No. 1 engine	15	45	43	38.5	58.5	37.5	27.5	37.5	37	30	25	18.5	19
No. 2 engine	18	------	43	38.5	38.5	37.5	27.5	37.5	37	30	30	15.5	19
No. 5 engine	18	------	43	38.5	58.5	37.5	27.5	37.5	57	30	30.5	18.6	19
No. 4 engine	16	------	43	38.5	38.5	37.5	27.5	37.5	36	30	28	18.5	19
Engine speed, rpm:													
No. 1 engine	1210	2450	2500	2300	2300	2300	1900	2300	2300	2200	2050	1800	1800
No. 2 engine	1250	------	2500	2300	2300	2300	1900	2300	2300	2200	2200	1800	1800
No. 5 engine	1350	------	2500	2300	2300	2300	1900	2300	2300	2200	2200	1800	1800
No. 4 engine	1275	------	2500	2300	2300	2300	1900	2300	2300	2200	2200	1800	1800
Indicated airspeed, mph	------	------	----	140	138	136	129	158	130	139	118	148	153
Pressure altitude, ft	Sea level	Sea level	Sea level	3000 7000	8,000 12,000	18,000 17,000	18,000	23,000 27,000	28,000 52,000	30,000	34,600	28,500 23,500	6500 3500
Mixture setting, automatic rich or lean	A.R.	A.R.	A.R.	A.R.	A.R.	A.R.	A.L.	A.R.	A.R.	A.R.	A.R.	A.L.	A.L.
Temperatures, °F:													
Ambient air	56	66	77	72	59	41	28	5	-17	-20	-40	-5	70
T_{43}, exhaust gas out	945	------	------	1496	1515	1513	------	1550	1819	1819	1500	1355	------
T_{44}, exhaust stack wall at T_{43}	290	------	------	592	510	607	604	1018	------	606	985	767	422
T_{45}, exhaust stack wall at T_{43}	631	------	------	1112	1158	1173	1174	1225	1285	1254	1219	893	850
T_{46}, exhaust stack wall at T_{45}	494	------	------	560	580	620	577	------	748	573	602	732	555
T_{49}, air out (Survey)	258	------	------	421	455	467	449	528	579	560	500	291	272
T_{50}, air out (Survey)	296	------	------	426	456	465	449	524	585	568	484	295	275
T_{51}, air out (Survey)	301	466	397	427	450	457	442	506	569	543	478	298	280
T_{52}, air out (Survey)	302	------	------	425	445	449	435	491	553	524	469	301	281
T_{53}, air out (Survey)	290	------	------	418	453	435	418	468	518	488	482	298	274
T_{54}, stack hood, top, fwd. of dam	121	------	------	274	316	346	437	340	378	400	509	255	221
T_{55}, nacelle shroud, top, forward	152	------	------	332	584	427	588	518	511	560	505	186	157
T_{56}, nacelle shroud, top, aft	181	------	250	440	477	500	440	547	634	562	530	256	198
T_{57}, air outlet duct	176	------	------	472	497	506	472	556	------	------	544	366	301
Pressures:													
[1]P_{21}, exhaust gas in, static	30.5	------	38	51.3	28.4	26.2	19.2	24.4	24.5	19.5	23.5	13.0	24.5
[2]$P_{21}-P_{22}$, exhaust gas ΔP_E	-0.1	------	-5	-4.0	-3.0	-3.0	-1.9	-2.8	-2.4	-2.5	-----	-1.0	-1.1
[3]P_{23}, air in static, center	1.5	------	------	11.6	11.4	11.5	9.1	10.4	9.4	10.1	7.8	10.5	11.3
[3]P_{24}, air in total, inboard	1.5	------	------	13.5	11.3	11.5	10.3	10.6	9.3	10.4	7.5	11.0	12.2
[3]P_{25}, air in total, center	1.7	------	------	13.0	12.2	12.5	10.6	11.5	9.8	11.2	8.2	11.2	12.2
[3]P_{25}, air in total, outboard	2.1	------	------	13.0	12.2	12.2	10.5	10.8	10.1	11.2	8.0	11.3	12.5
[3]P_{27}, air out, static	0.4	------	------	-1.8	-1.9	-1.5	-1.8	-1.8	-1.8	-1.8	-1.8	-2.0	-1.9

[1]Inches of mercury, absolute.
[2]Inches of water.
[3]Inches of water referred to ambient static pressure.

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TABLE VII. - DATA RECORDED FOR EXCHANGER 7 TESTED IN NACELLE 3 OF THE B-17F AIRPLANE

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Run number	1	2	3	4	5	6	7	8	9	10	11	12	13
Flight conditions	Ground	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Climb	Level	Level	Descent	Descent
Manifold pressure, in. Hg:													
No. 1 engine	16	--	41	38.5	38.5	38.0	27.5	37.5	37	30	25	18	19.0
No. 2 engine	16	--	45	38.5	38.5	38.0	27.5	37.5	37	30	30	18	19.0
No. 3 engine	16	45	42	38.5	38.5	38.0	27.5	37.5	37	30	30.5	18	19.0
No. 4 engine	16	--	43	38.5	38.5	38.0	27.5	37.5	37	30	28	18.5	19.0
Engine speed, rpm:													
No. 1 engine	1210	--	2500	2300	2300	2300	1900	2300	2300	2200	2050	1700	1800
No. 2 engine	1250	--	2500	2300	2300	2300	1900	2300	2300	2200	2200	1700	1800
No. 3 engine	1350	2500	2500	2300	2300	2300	1900	2300	2300	2200	2200	1800	1800
No. 4 engine	1275	--	2500	2300	2300	2300	1900	2300	2300	2200	2200	1800	1800
Indicated airspeed, mph:	--	--	--	143	145	138	137	129	130	145	114	148	148
Pressure altitude, ft:	Sea level	Sea level	Sea level	3,000 7,000	8,000 12,000	13,000 17,000	18,180	23,000 27,000	28,000 32,000	30,000	34,600	26,500 23,500	6,500 3,500
Mixture setting, automatic rich or lean:	A.R.	A.R.	A.R.	A.L.	A.R.	A.R.	A.L.	A.R.	A.R.	A.L.	A.R.	A.L.	A.L.
Temperatures, °F:													
Ambient air	66	66	--	77	59	41	28	3	-13	-20	-40	-4	72
T_{20}, exhaust gas in	1105	--	1547	1563	1606	1601	1635	1565	1573	1559	1575	1499	1472
T_{21}, exhaust stack wall at T_{20}	478	--	--	1122	1156	1178	1185	1210	1245	1192	1240	1046	899
T_{22}, exhaust stack wall at T_{20}	480	--	--	--	--	874	1068	--	--	--	--	--	--
T_{24}, exhaust gas out	920	--	1392	1432	1468	1476	1475	1455	1478	1339	1470	--	1262
T_{25}, exhaust stack wall at T_{24}	430	--	--	1028	1044	1072	951	1055	1089	1011	1020	783	589
T_{26}, exhaust stack wall at T_{24}	360	--	--	711	716	747	650	794	839	721	478	510	370
T_{30}, air out (survey)	319	--	428	479	492	501	470	511	540	481	566	387	334
T_{31}, air out (survey)	324	--	413	490	501	509	480	520	550	484	576	393	340
T_{32}, air out (survey)	322	492	413	490	501	509	476	517	546	478	569	393	341
T_{33}, air out (survey)	323	--	422	486	500	508	475	520	550	478	572	390	338
T_{34}, air out (survey)	322	--	422	487	501	508	474	517	543	481	569	390	340
T_{35}, shroud hood, inboard, forward of dam	137	--	--	351	376	460	358	410	450	360	500	249	222
T_{36}, nacelle shroud, inboard, fwd	158	--	226	342	376	429	372	492	547	358	596	262	198
T_{37}, nacelle shroud, inboard, aft	161	--	223	298	320	361	314	440	518	413	618	216	158
T_{38}, air outlet duct	147	--	--	--	449	458	422	467	491	436	508	673	308
Pressures:													
[1] P_{11}, exhaust gas in, static	30.5	35.9	34.0	30.0	28.0	26.8	20.0	24.9	24.4	19.8	20.0	14.0	24.5
[2] $P_{11}-P_{12}$, gas static ΔP_g	0.6	15.0	11.0	10.4	10.5	12.3	5.9	15.0	15.5	11.9	11.2	4.0	1.4
[3] P_{13}, air in static	2.4	--	--	12.8	12.6	12.3	11.8	10.6	10.6	11.8	8.5	11.3	10.9
[3] P_{14}, air in total, top	2.2	--	--	13.9	13.9	13.2	13.2	11.2	11.0	12.2	9.0	12.2	12.2
[3] P_{15}, air in total, center	2.2	--	--	13.5	13.4	13.2	13.2	11.3	11.6	12.2	8.0	12.4	12.0
[3] P_{16}, air in total, bottom	2.8	--	--	14.2	14.0	13.4	13.4	11.3	11.2	12.4	9.3	12.5	12.2
[3] P_{17}, air out static	0.0	--	--	-0.5	-0.9	-0.4	-0.5	0.5	0.5	0.3	0.5	-0.8	-1.8

[1] Inches of mercury, absolute.
[2] Inches of water.
[3] Inches of water, referred to ambient static pressure.

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TABLE VIII.- GENERAL PERFORMANCE CHARACTERISTICS OF EXCHANGER 1
TESTED IN NACELLE 1 OF THE B-17F AIRPLANE

Run Number	1	2	3	4	5	6	7	8	9	10	11
Flight conditions	Ground run	Take-off	Climb	Climb	Climb	Level	Climb	Level	Descent	Descent	Descent
Pressure altitude, ft	Sea level	Sea level	3,000 7,000	8,000 12,000	12,400 16,400	18,000	20,300 24,300	24,800	24,500 21,500	17,200 14,200	8,000 5,000
Indicated airspeed, mph	0	-------	134	135	133	128	133	129	153	148	160
Ambient air temperature, °F	66	62	57	48	17	14	12	-9	-2	18	53
Engine speed, rpm	1150	2500	2300	2300	2300	1800	2300	1900	1800	1800	1800
Manifold pressure, in. Hg	16	44	37	38.5	38.5	28	37	26.5	20	19	20
Exhaust-gas flow rate, lb/hr	1150	-------	5900	6300	6300	3600	5900	3600	2600	2400	2500
Corrected exhaust-gas temperature in, °F	-------	-------	1624	1634	1818	1768	1646	1820	1695	1639	1738
Corrected exhaust-gas temperature out, °F	1020	-------	1532	1550	1545	1662	-------	-------	-------	-------	-------
Air-flow rate, lb/hr	1900	-------	3200	2800	2500	2120	2040	1780	2120	2570	3450
Air temperature out, °F	301	464	449	468	463	449	510	476	398	335	295
Air-temperature rise, °F	235	402	392	418	446	435	498	485	398	317	242
Rate of heat transfer, 1000 Btu/hr	108	-------	305	285	270	223	247	210	204	196	200
Air-side static pressure drop, in. H_2O	1.2	-------	12.3	12.7	12.2	10.5	11.9	11.0	12.8	12.2	13.8
Exhaust-side static pressure drop, in. H_2O	-------	3.5	2.9	3.2	3.3	-------	-------	-------	-------	-------	-------

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TABLE IX.-GENERAL PERFORMANCE CHARACTERISTICS OF EXCHANGER 2 TESTED IN NACELLE 3 OF THE B-17F AIRPLANE

Run number	1	2	3	4	5	6	7	8	9	10	11
Flight conditions	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Level	Descent	Descent	Descent
Pressure altitude, ft	sea level	sea level	3,300 7,300	8,000 12,000	12,000 16,000	18,300	20,800 24,800	25,000	24,500 21,500	21,000 18,000	7,000 4,000
Indicated airspeed, mph	0	-----	135	133	133	128	133	129	138	158	165
Ambient air temperature, °F	66	62	58	50	36	10	12	-9	-2	3	58
Engine speed, rpm	1150	2500	2300	2300	2300	1825	2300	2040	1800	1800	1800
Manifold pressure, in. Hg	16	44	37	38	38	25	37	27	19.5	21	20
Exhaust-gas flow rate, lb/hr	1140	----	5900	6100	6100	3300	5900	4000	2490	2700	2500
Corrected exhaust-gas temperature in, °F	1242	----	1390	1399	1555	1646	1570	1768	1616	1430	1330
Corrected exhaust-gas temperature out, °F	981	----	992	962	1389	1280	1428	890	1370	1388	1292
Air-flow rate, lb/hr	1990	----	3530	3170	2860	2540	2390	2030	2060	2580	3600
Air temperature out, °F	309	402	421	431	438	380	488	475	371	341	285
Air-temperature rise, °F	243	340	363	381	402	370	476	484	373	338	227
Rate of heat transfer, 1000 Btu/hr	116	----	310	292	278	227	276	238	184	209	196
Air-side static pressure drop, in. H_2O	0.1	----	5.4	5.3	6.2	4.7	6.5	4.6	4.7	6.0	6.2
Exhaust-side static pressure drop, in. H_2O	----	15	26.5	28	29	11.3	33	17	10.5	----	----

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TABLE X.- GENERAL PERFORMANCE CHARACTERISTICS OF EXCHANGER 3
TESTED IN NACELLE 4 OF THE B-17F AIRPLANE

Run number	1	2	3	4	5	6	7	8	9	10	11
Flight conditions	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Level	Descent	Descent	Descent
Pressure altitude, ft	sea level	sea level	3,200 7,200	8,400 12,400	13,300 17,300	18,000	20,300 24,300	25,100	24,700 21,700	20,000 17,000	7,000 4,000
Indicated airspeed, mph	0	---	133	133	135	128	134	129	143	150	158
Ambient air temperature, °F	66	62	54	39	32	16	16	-11	-6	16	44
Engine speed, rpm	1200	2500	2300	2300	2300	1825	2300	1900	1800	1800	1800
Manifold pressure, in. Hg	16	44	39	38	38	28	37	27.5	19.5	19.5	19
Exhaust-gas flow rate, lb/hr	1250	----	6300	6100	6100	3700	5900	3700	2500	2500	2400
Corrected exhaust-gas temperature in, °F	1184	----	1570	1570	1610	1722	1642	1765	1640	1654	1581
Corrected exhaust-gas temperature out, °F	947	----	1444	1460	1468	1516	1514	----	1430	1420	1296
Air-flow rate, lb/hr	1980	----	3920	3300	2940	2820	2420	2220	2550	3070	4260
Air temperature out, °F	298	375	399	407	426	367	463	403	321	311	255
Air-temperature rise, °F	232	313	345	368	394	351	447	414	327	295	211
Rate of heat transfer, 1000 Btu/hr	111	----	326	293	279	239	262	222	202	217	216
Air-side static pressure drop, in. H_2O	0.1	----	8.2	8.6	9.0	7.9	8.6	7.6	7.5	8.0	7.3
Exhaust-side static pressure drop, in. H_2O	----	8.5	----	----	----	3.6	----	12	7	1.6	4.6

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TABLE XI.- GENERAL PERFORMANCE CHARACTERISTICS OF EXCHANGER 4 TESTED IN NACELLE 4 OF THE B-17F AIRPLANE

Run number	1	2	3	4	5	6	7	8	9	10	11	12	13
Flight conditions	Ground	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Climb	Level	Descent	Descent	Descent
Pressure altitude, ft	sea level	sea level	sea level	5,000 9,000	10,000 14,000	13,800 17,800	18,200	23,000 27,000	28,000 32,000	30,000	28,000 25,000	20,000 17,000	5,800 2,800
Indicated airspeed, mph	0	0	-----	133	133	133	134	136	135	137	133	140	160
Ambient air temperature, °F	70	70	-----	68	59	48	28	0	-24	-26	-18	17	68
Engine speed, rpm	1225	2425	2500	2300	2300	2300	1800	2300	2300	2100	1820	1825	1820
Manifold pressure, in. Hg	16	45.5	44.0	39.0	38.0	37.5	27.2	37.0	37.0	27.0	21.8	18.0	19.8
Exhaust-gas flow rate, lb/hr	1400	7800	7600	6200	6100	6000	3400	5900	5900	4100	2800	2300	2500
Corrected exhaust-gas temperature, in, °F	1230	1190	----	1657	1670	1680	1745	1720	1746	----	1670	1610	1589
Corrected exhaust-gas temperature out, °F	979	----	----	1521	1524	1538	1570	1586	1616	1689	1497	1422	1354
Air-flow rate, lb/hr	1680	2700	----	3950	3580	3240	2930	2590	2250	2210	2450	3010	4510
Air temperature out, °F	306	469	----	387	385	388	346	397	400	372	282	274	259
Air-temperature rise, °F	236	399	----	319	326	340	318	397	424	398	300	257	191
Rate of heat transfer, 1000 Btu/hr	95	260	----	305	283	265	224	248	230	212	177	186	208
Air-side static pressure drop, in. H_2O	0.9	4.1	----	7.0	7.6	7.2	6.5	6.9	7.2	7.4	6.3	5.8	6.5
Exhaust-side static pressure drop, in. H_2O	0.4	10.5	10.0	8.0	8.1	6.8	3.0	6.8	6.0	6.1	2.8	2.3	0.6

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TABLE XII.-GENERAL PERFORMANCE CHARACTERISTICS OF EXCHANGER 5 TESTED IN NACELLE 4 OF THE B-17F AIRPLANE

Run number	1	2	3	4	5	6	7	8	9	10	11	12	13
Flight conditions	Ground	Ground	Climb	Climb	Climb	Level	Climb	Climb	Level	Level	Descent	Descent	Descent
Pressure altitude, ft	sea level	sea level	3,500 6,500	8,500 11,500	13,500 16,500	18,100 ------	23,500 26,500	28,500 31,500	30,000	34,600	26,500 23,500	19,500 16,500	6,500 3,500
Indicated airspeed, mph	-----	-----	134	135	136	135	131	130	143	115	148	148	148
Ambient air temperature, °F	66	66	72	59	41	23	9	-13	-19	-40	-4	23	66
Engine speed, rpm	1275	2450	2300	2300	2300	1900	2300	2300	2200	2200	1800	1800	1800
Manifold pressure, in. Hg	16	45	38.5	38	37.5	27.5	37	37	30	28	19.5	17.5	18.5
Exhaust-gas flow rate lb/hr	1350	----	6100	6100	6000	3600	5900	5900	4500	4200	2500	2200	2300
Corrected exhaust-gas temperature in, °F	1283	1681	1616	1658	1668	1765	1671	1697	1789	----	----	----	----
Corrected exhaust-gas temperature out, °F	----	----	1531	1539	1543	1582	1569	1657	1654	1733	1451	1393	1366
Air-flow rate, lb/hr	1625	3080	4420	3950	3550	3350	2630	2270	2640	1680	3030	3600	4670
Air temperature out, °F	342	496	400	413	425	375	475	507	439	567	317	277	263
Air-temperature rise, °F	276	430	328	354	384	352	466	520	458	607	321	254	197
Rate of heat transfer, 1000 Btu/hr	108	320	351	338	330	286	297	286	293	247	236	221	223
Air-side static pressure drop, in. H_2O	1.1	----	8.2	8.1	7.8	7.8	8.0	7.9	8.3	6.7	7.8	7.5	7.2
Exhaust-side static pressure drop, in. H_2O	0.4	5.8	3.8	4.8	4.6	2.4	4.6	5.4	4.8	----	----	----	0

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TABLE XIII.- GENERAL PERFORMANCE CHARACTERISTICS OF EXCHANGER 6 TESTED IN NACELLE 1 OF THE B-17F AIRPLANE

Run number	1	2	3	4	5	6	7	8	9	10	11	12	13
Flight conditions	Ground	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Climb	Level	Level	Descent	Descent
Pressure altitude, ft	sea level	sea level	sea level	3,000 7,000	8,000 12,000	13,000 17,000	18,100	23,000 27,000	28,000 32,000	30,000	34,600	26,500 23,500	6,500 3,500
Indicated airspeed, mph	-----	-----	-----	140	138	136	129	136	130	139	118	148	153
Ambient air temperature, °F	66	66	77	72	59	41	28	5	-17	-20	-40	-6	70
Engine speed, rpm	1210	2450	2500	2300	2300	2300	1900	2300	2300	2200	2050	1800	1800
Manifold pressure, in. Hg	16	45	43	38.5	38.5	37.5	27.5	37.5	37	30	25	18.5	19
Exhaust-gas flow rate, lb/hr	1250	-----	-----	6300	6300	6000	3600	6000	5900	4500	3700	2300	2400
Corrected exhaust-gas temperature out, °F	1063	-----	-----	1565	1585	1583	-----	1620	1689	1759	1640	1495	-----
Air-flow rate, lb/hr	1240	-----	3250	3330	2910	2660	2320	2050	1670	1810	1440	2370	3690
Air temperature out, °F	295	486	397	424	448	455	439	503	561	536	479	297	276
Air-temperature rise, °F	229	420	320	352	389	414	411	498	578	556	519	363	206
Rate of heat transfer, 1000 Btu/hr	68.5	-----	251	284	281	266	230	247	234	244	181	173	183
Air-side static pressure drop, in. H_2O	-----	-----	-----	12.3	11.5	11.8	10.1	11.4	10.4	11.2	9.0	11.6	11.8
Exhaust-side static pressure drop, in. H_2O	-0.1	-----	-6.0	-4.0	-3.9	-3.0	-1.9	-2.8	-2.4	-2.5	-----	-1.0	-1.1

TABLE XIV.- GENERAL PERFORMANCE CHARACTERISTICS OF EXCHANGER 7
TESTED IN NACELLE 3 OF THE B-17F AIRPLANE

Run number	1	2	3	4	5	6	7	8	9	10	11	12	13
Flight conditions	Ground	Ground	T.O.	Climb	Climb	Climb	Level	Climb	Climb	Level	Level	Descent	Descent
Pressure altitude, ft	sea level	sea level	sea level	3,000 7,000	8,000 12,000	13,000 17,000	18,180	23,000 27,000	28,000 32,000	30,000	34,600	28,500 23,500	6,500 3,500
Indicated airspeed, mph	------	------	------	143	145	138	137	129	130	145	114	148	148
Ambient air temperature, °F	66	66	------	77	59	41	28	3	-13	-20	-40	-4	72
Engine speed, rpm	1350	2500	2500	2300	2300	2300	1900	2300	2300	2200	2200	1800	1800
Manifold pressure, in. Hg	16	45	42	38.5	38.5	38	27.5	37.5	37	30	30.5	18	19
Exhaust-gas flow rate, lb/hr	1500	------	------	6300	6300	6100	3600	6000	5900	4500	4550	2250	2400
Corrected exhaust-gas temperature in, °F	1175	------	1617	1633	1876	1671	1775	1635	1643	1699	1715	1639	1622
Corrected exhaust-gas temperature out, °F	990	------	1462	1502	1538	1646	1615	1525	1548	1479	1610	----	1402
Air-flow rate, lb/hr	2310	------	------	4550	3930	3470	3330	2670	2310	2450	1790	2910	4580
Air temperature out, °F	322	492	420	486	499	507	475	517	546	480	570	391	339
Air-temperature rise, °F	256	426	------	409	440	466	447	514	559	500	610	395	267
Rate of heat transfer, 1000 Btu/hr	143	------	------	451	418	391	360	332	313	294	265	277	295
Air-side static pressure drop, in. H_2O	2.5	------	------	13.6	13.7	12.9	12.5	10.3	10.3	11.7	8.1	12.3	13.0
Exhaust-side static pressure drop, in. H_2O	0.6	15	11	10.4	10.5	12.3	5.9	15	15.5	11.9	11.2	4.0	1.4

TABLE XV

OBSERVATIONS OF EXHAUST FLAMING AND EXHAUST-SYSTEM GLOWING OF THE B-17F AIRPLANE WITH VARIOUS HEAT EXCHANGERS INSTALLED IN NACELLES 1, 3, AND 4

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Test condition	Pressure altitude (ft)	Engine manifold pressure (in. Hg)	Engine speed (rpm)	Mixture, automatic rich or lean	Indicated airspeed (mph)	Visual observations: Exhaust flame	Exhaust-system glowing: Stack forward of exchanger	Stack aft of exchanger	Supercharger: Turbine	Supercharger: Waste gate	General comments
Exchanger 1 installed in nacelle 1. Flights made from 9:30 P.M. to 11:00 P.M., May 28, 1943 for conditions 1-4, and from 9:00 P.M. to 11:00 P.M., June 2, 1943 for conditions 5-10											
1	5000	27	1450	A.L.	---	Yes	Yes	---	Yes	Yes	Observations made from ball turret; one observer; intensity of flaming and glowing greater for condition 2.
2	5000	38.5	2300	A.R.	---	Yes	Yes	---	Yes	Yes	
3	500	31	2100	A.L.	---	No	No	No	No	No	Observations were made from the ground; two observers.
4	300	31	2100	A.L.	---	No	Yes	Yes	Yes	---	
5	7000	27	1500	A.L.	---	No	Yes	Yes	Yes	---	Observations were made from an accompanying airplane at an estimated distance of 300 feet, from each side and from below the B-17F airplane; two observers; intensity of glow was greatest for condition 10 and least for 5; observations were also made from the ball turret and for conditions 5, 6, 7, 8, and 10 were essentially the same as for 1 and 2; the flame and glow were most intense for condition 10 and least for 5; the flame and glow were more intense for condition 7 than for 8.
6	7000	38.5	2300	A.R.	---	No	Yes	Yes	Yes	---	
7	7000	31	2100	A.L.	---	No	Yes	Yes	Yes	---	
8	7000	31	2100	A.R.	---	No	Yes	Yes	Yes	---	
9	7000	15-18	2100-2300	A.R.	---	No	No	No	No	No	
10	7000	46	2500	A.R.	---	No	Yes	Yes	Yes	---	
Exchanger 2 installed in nacelle 3. Flights made from 9:30 P.M. to 11:00 P.M., May 28, 1943 for conditions 1-4, and from 9:00 P.M. to 11:00 P.M., June 2, 1943 for conditions 5 & 6											
1	5000	27	1450	A.L.	---	No	---	---	No	Yes	Observations were made from the ball turret of the B-17F airplane; one observer.
2	5000	38.5	2300	A.R.	---	Yes	---	---	Yes	Yes	
3	500	31	2100	A.L.	---	No	No	No	No	No	Observations were made from the ground; two observers.
4	300	31	2100	A.L.	---	No	No	No	No	No	
5	7000	27	1500	A.L.	---	No	Yes	Yes	Yes	---	Observations were made from an accompanying airplane at an estimated distance of 300 feet, from each side and from below the B-17F; two observers.
6	7000	15-18	2100-2300	A.R.	---	No	No	No	No	No	
Exchanger 3 installed in nacelle 4. Flights made from 9:30 P.M. to 11:00 P.M., May 28, 1943 for conditions 1-4, and from 9:00 P.M. to 11:00 P.M., June 2, 1943 for conditions 5-10											
1	5000	27	1450	A.L.	---	No	Yes	---	---	Yes	Observations made from ball turret; one observer; for condition 2, sides of exchanger also glowed.
2	5000	38.5	2300	A.R.	---	Yes	Yes	Yes	Yes	---	
3	500	31	2100	A.L.	---	No	No	No	No	No	Observations were made from the ground; two observers.
4	300	31	2100	A.L.	---	No	No	No	No	No	
5	7000	27	1500	A.L.	---	No	Yes	Yes	Yes	---	Observations were made from an accompanying airplane at an estimated distance of 300 feet, from each side and from below the B-17F; two observers; observations were also made from the ball turret; flame and glowing of the exhaust system were observed for conditions 5, 6, 7, 8, and 10, being the most intense for 10, and more intense for 7 than for 8; no flame or glow were visible for 9.
6	7000	38.5	2300	A.R.	---	No	Yes	Yes	Yes	---	
7	7000	31	2100	A.L.	---	No	Yes	Yes	Yes	---	
8	7000	31	2100	A.R.	---	No	Yes	Yes	Yes	---	
9	7000	15-18	2100-2300	A.R.	---	No	No	No	No	No	
10	7000	46	2500	A.R.	---	No	Yes	Yes	Yes	---	
Exchanger 4 installed in nacelle 4. Flight made from 11:00 P.M., July 22, 1943 to 2:00 A.M., July 23, 1943											
1	20,000	38	2300	A.R.	150	No	Yes	Yes	Yes	Yes	Observations were made from an accompanying airplane at an estimated distance of 300 feet, from each side and from below the B-17F; two observers; the glow was most intense for conditions 1 and 4.
2	2,500	29	2000	A.L.	165	No	Yes	Yes	Yes	No	
3	2,700	29	2000	A.R.	165	No	Yes	No	Yes	No	
4	2,600	38.5	2300	A.R.	145	No	Yes	Yes	Yes	Yes	
5	2,800	38.5	2300	A.R.	190	No	Yes	Yes	Yes	Yes	
Exchanger 6 installed in nacelle 1. Flight made from 11:00 P.M., July 22, 1943 to 2:00 A.M., July 23, 1943											
1	20,150	38	2300	A.R.	150	No	Yes	---	Yes	Yes	Observations were made from an accompanying airplane at an estimated distance of 300 feet, from each side and from below the B-17F; two observers.
2	2,500	29	2000	A.L.	165	No	Yes	---	Yes	---	
3	2,700	29	2000	A.R.	165	No	Yes	---	Yes	---	
4	2,300	38.5	2300	A.R.	155	No	Yes	Yes	Yes	---	
5	2,800	38.5	2300	A.R.	190	No	Yes	Yes	Yes	---	
Exchanger 7 installed in nacelle 3. Flight made from 11:00 P.M., July 22, 1943 to 2:00 A.M., July 23, 1943											
1	20,100	37.5	2300	A.R.	150	No	Yes	Yes	Yes	---	Observations were made from an accompanying airplane at an estimated distance of 300 feet, from each side and from below the B-17F; two observers.
2	2,500	29	2000	A.L.	165	No	Yes	No	Yes	No	
3	2,700	29	2000	A.R.	165	No	Yes	---	Yes	---	
4	2,800	38.5	2300	A.R.	155	No	Yes	Yes	Yes	---	
5	2,800	38.5	2300	A.R.	190	No	Yes	Yes	Yes	---	

TABLE XVI.- TEST RESULTS OF THE FINAL INSTALLATION OF EXCHANGERS 3, 5, AND 7 IN NACELLES 4, 1, AND 3, RESPECTIVELY, OF THE B-17F AIRPLANE

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Flight condition	Pressure altitude (ft)	Corrected indicated airspeed, (mph)	Engine speed (rpm)	Manifold pressure (in. Hg.)	Ambient air temperature (°F)	Air temperature out, (°F)	Air-temperature rise, (°F)	Air-flow rate (lb/hr)	Rate of heat transfer, (1000 Btu/hr)
Exchanger 3 installed in nacelle 4									
Climb	4-6000	137	2300	38	52	350	298	5070	363
Climb	9-11000	137	2300	38	46	365	319	4500	345
Climb	14-16000	141	2300	38	28	370	342	4140	340
Level	18000	150	2000	27	21	335	314	4240	319
Climb	245-25000	141	2300	38	-9	370	379	3460	314
Climb	295-30500	137	2300	38	-31	370	401	3020	289
Descent	55-4500	146	1800	19	57	240	183	5490	241
Exchanger 5 installed in nacelle 1									
Climb	4-6000	137	2300	39	52	450	398	4190	400
Climb	9-11000	137	2300	38	46	460	414	3750	373
Climb	14-16000	134	2300	38	32	470	438	3250	342
Level	18000	150	2000	27	21	470	449	3360	362
Climb	245-25500	143	2300	38	-6	530	536	2750	354
Climb	295-30500	137	2300	38	-31	565	596	2310	331
Descent	55-4500	146	1800	19	57	280	223	4370	234
Exchanger 7 installed in nacelle 3									
Climb	4-6000	137	2300	38	52	400	348	4820	402
Climb	9-11000	137	2300	38	46	407	361	4300	372
Climb	14-16000	134	2300	38	32	407	375	3820	343
Level	18000	150	2000	27	21	407	386	3470	321
Climb	245-25500	143	2300	38	-6	435	441	3040	321
Climb	295-30500	137	2300	38	-31	443	474	2720	310
Descent	55-4500	146	1800	19	57	290	233	4800	268

TABLE XVII.- COMPARISON OF DESIGN REQUIREMENTS AND EVALUATED PERFORMANCE OF THE HEAT EXCHANGERS TESTED IN THE B-17F AIRPLANE

	Design requirements, outboard nacelles	Performance						Design requirements, inboard nacelles	Performance		
		Exchanger 1	Exchanger 2	Exchanger 3	Exchanger 4	Exchanger 5	Exchanger 6		Exchanger 5	Exchanger 6	Exchanger 7
Pressure altitude, ft	18,000	18,000	18,300	18,000	18,200	18,100	18,100	35,000	34,600	34,600	34,600
Indicated airspeed, mph	155	128	128	128	134	135	129	140	115	118	114
Ambient air temperature, °F	0	14	10	16	28	23	28	-65	-40	-40	-40
Air-side total pressure drop, in. H_2O	4.0	[a]9.3	[a]3.1	[a]7.1	[a]5.1	[a]4.7	[a]9.2	3.5	[a]4.3	[a]7.1	[a]7.2
Air-side static pressure drop, in. H_2O	----	10.5	4.7	7.9	6.5	7.8	10.1	----	6.7	9.0	8.1
Air out temperature, °F	295-325	449	380	367	346	375	439	480-505	567	479	570
Air-temperature rise, °F	295-385	435	370	351	318	352	411	545-570	607	519	618
Air-flow rate, lb/hr	3,500	2,120	2,540	2,020	2,930	3,350	2,320	2,400	1,680	1,440	1,790
Rate of heat transfer, Btu/hr	250,000	229,000	227,000	239,000	224,000	286,000	230,000	320,000	247,000	181,000	265,000
Gas static pressure forward of exchanger, in. Hg	20	20	20	21	20.7	20.2	19.2	18.5	---	23.5	20.0
Gas-side total pressure drop, in. H_2O	7.3	---	---	---	---	---	---	7.3	---	---	---
Gas-side static pressure drop, in. H_2O	----	---	11.3	3.6	3.0	2.4	-1.9	----	---	---	11.2
Gas temperature, entering, °F	1,500	1,766	---	1,722	1,745	---	---	1,500	---	---	1,715
Gas-flow rate, lb/hr	3,000	3,600	3,300	3,600	3,400	3,600	3,600	4,000	4,200	3,100	4,550

[a]Calculated value (see text).

TABLE XVII.- COMPARISON OF DESIGN REQUIREMENTS AND EVALUATED PERFORMANCE OF THE HEAT EXCHANGERS TESTED IN THE B-17F AIRPLANE

	Design requirements, outboard nacelles	Performance						Design requirements, inboard nacelles	Performance		
		Exchanger 1	Exchanger 2	Exchanger 3	Exchanger 4	Exchanger 5	Exchanger 6		Exchanger 5	Exchanger 6	Exchanger 7
Pressure altitude, ft	18,000	18,000	18,300	18,000	18,200	18,100	18,100	35,000	34,600	34,600	34,600
Indicated airspeed, mph	155	128	128	128	134	135	129	140	115	118	124
Ambient air temperature, °F	0	14	10	16	28	25	28	-65	-40	-40	-40
Air-side total pressure drop, in. H_2O	4.0	[1]9.3	[1]3.1	[1]7.1	[1]5.1	[1]4.7	[1]9.2	3.5	[1]4.3	[1]7.1	[1]7.2
Air-side static pressure drop, in. H_2O	----	10.5	4.7	7.9	6.5	7.8	10.1	----	6.7	9.0	8.1
Air out temperature, °F	295-325	449	380	367	346	375	439	480-505	567	479	570
Air-temperature rise, °F	295-325	435	370	351	318	352	411	545-570	607	519	610
Air-flow rate, lb/hr	3,500	2,120	2,540	2,020	2,930	3,350	2,320	2,400	1,650	1,440	1,790
Rate of heat transfer, Btu/hr	250,000	223,000	227,000	239,000	224,000	286,000	230,000	320,000	247,000	181,000	265,000
Gas static pressure forward of exchanger, in. Hg	20	20	20	21	20.7	20.2	19.2	18.5	---	23.5	20.0
Gas-side total pressure drop, in. H_2O	7.3	---	---	---	---	---	---	7.3	---	---	---
Gas-side static pressure drop, in. H_2O	----	---	11.3	3.6	3.0	2.4	-1.9	----	---	---	11.2
Gas temperature, entering, °F	1,500	1,766	---	1,722	1,745	---	---	1,500	---	---	1,715
Gas-flow rate, lb/hr	3,000	3,600	3,300	3,600	3,400	3,600	3,600	4,000	4,200	3,700	4,550

[1]Calculated value (see text).

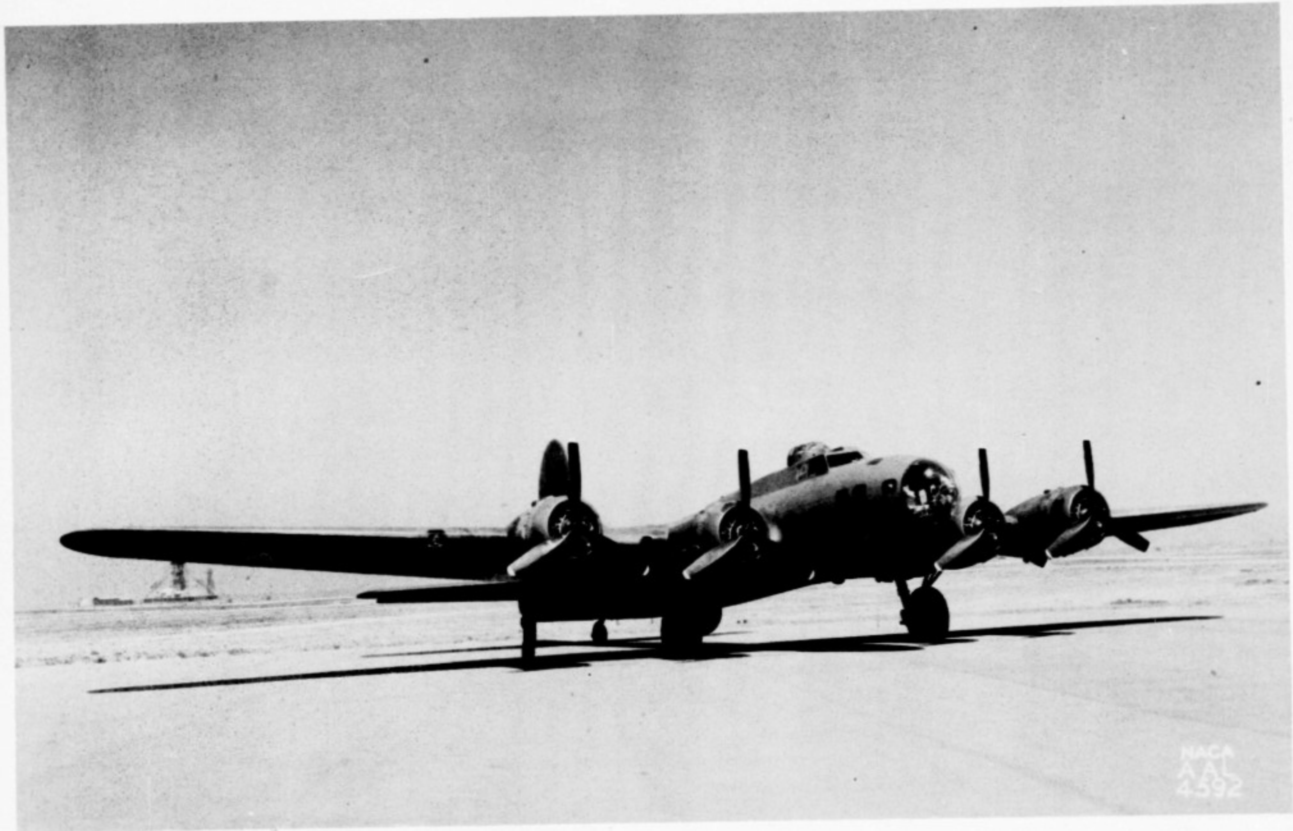

Figure 1.- B-17F airplane in which the heat exchangers were flight-tested.

Figure 2.- Heat exchanger used in the original thermal ice-prevention system of the B-17F airplane.

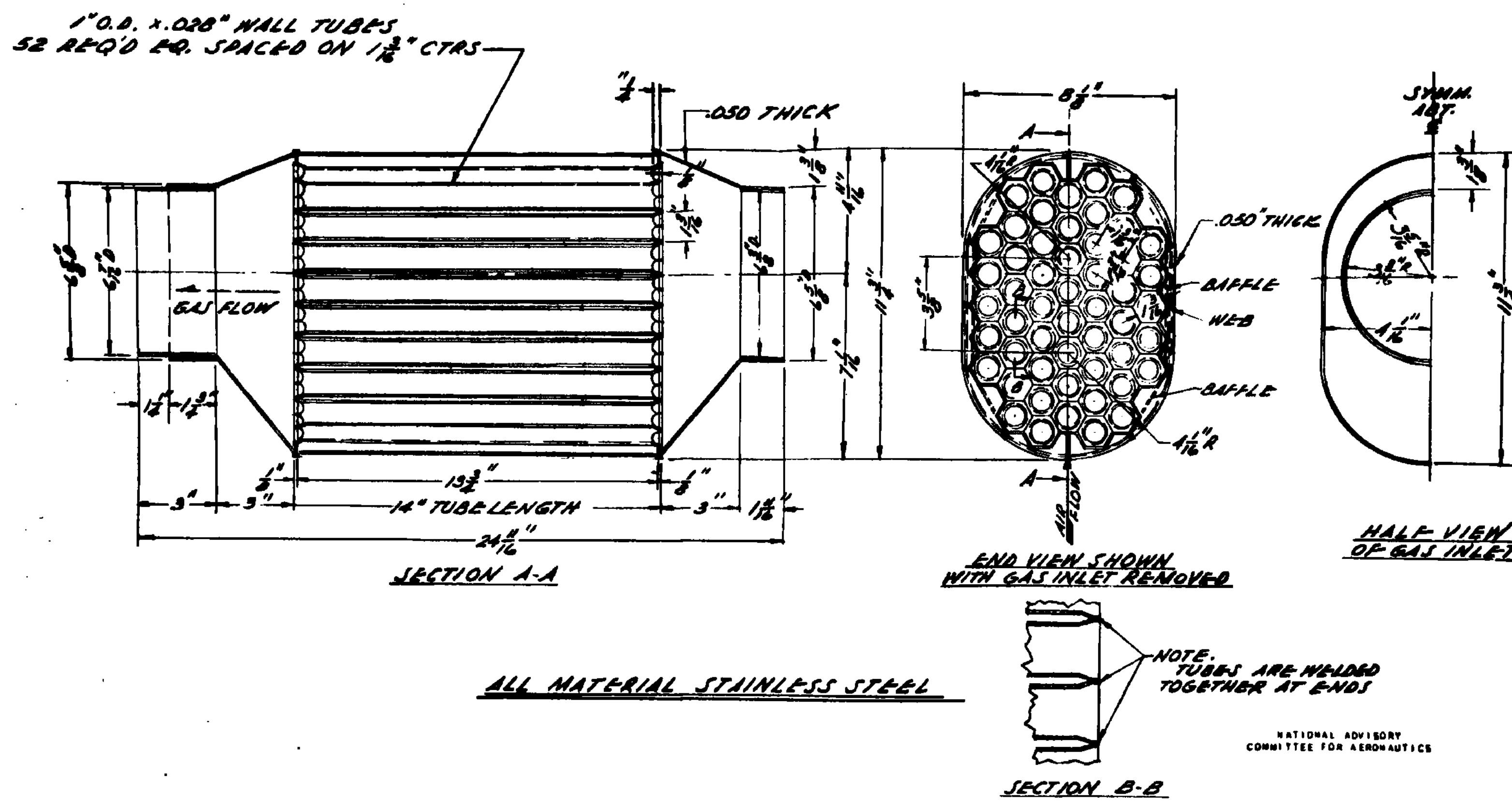

FIGURE 3. - HEAT EXCHANGER 1, TUBULAR TYPE, TESTED IN NACELLE 1 OF B-17F AIRPLANE.

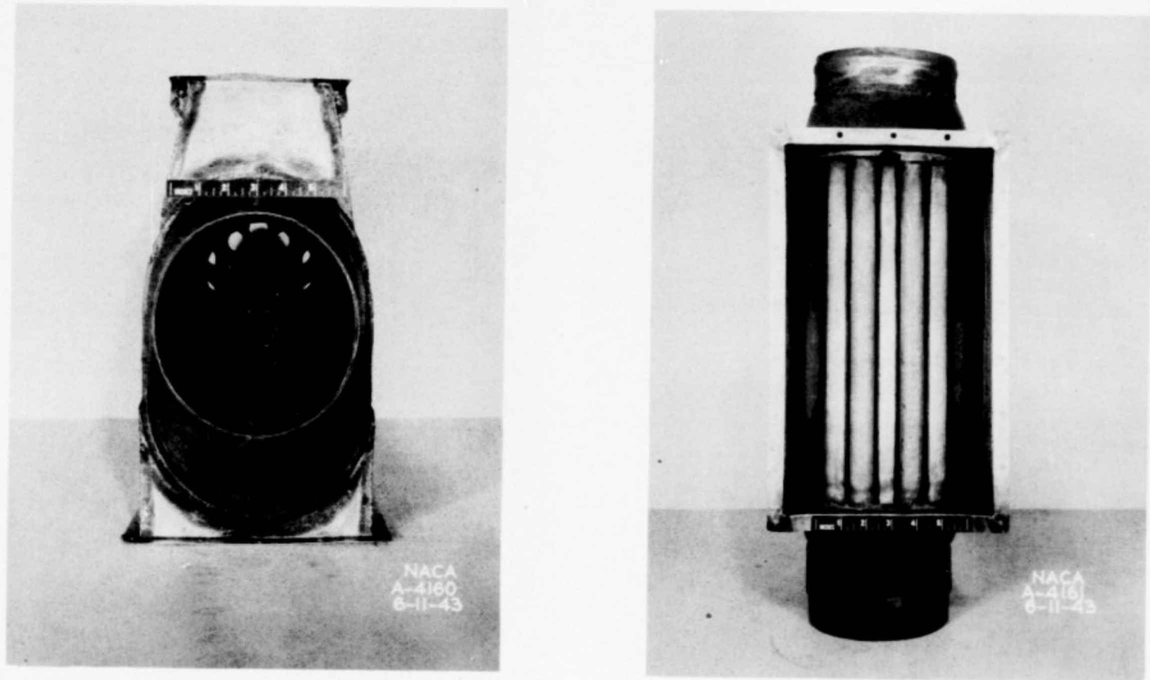

Figure 4.- Heat exchanger 1 as altered for installation in the B-17F airplane. Weight as shown, 33.8 pounds.

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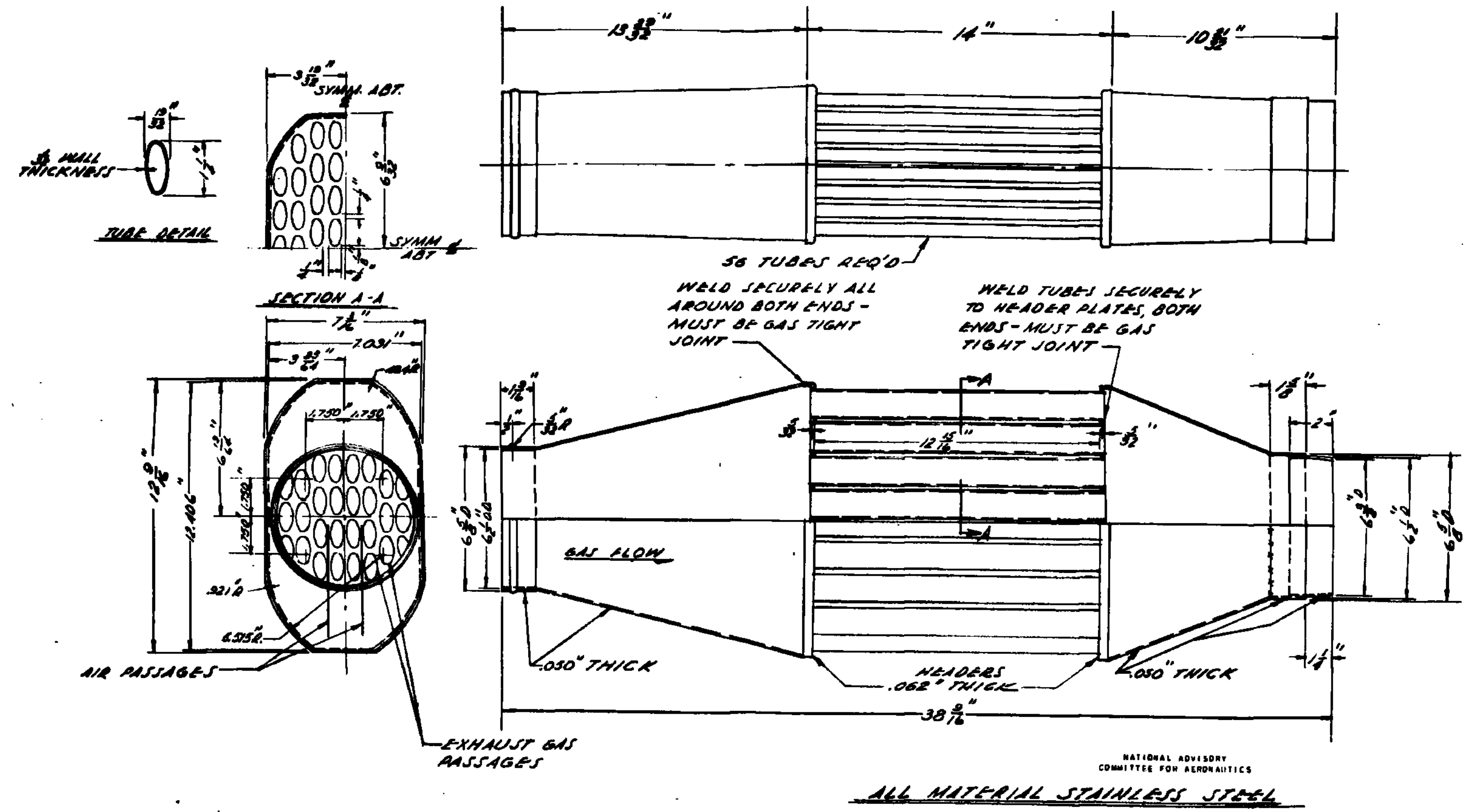

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FIGURE 5. - HEAT EXCHANGER 2, TUBULAR TYPE, TESTED IN NACELLE 3 OF B-17F AIRPLANE

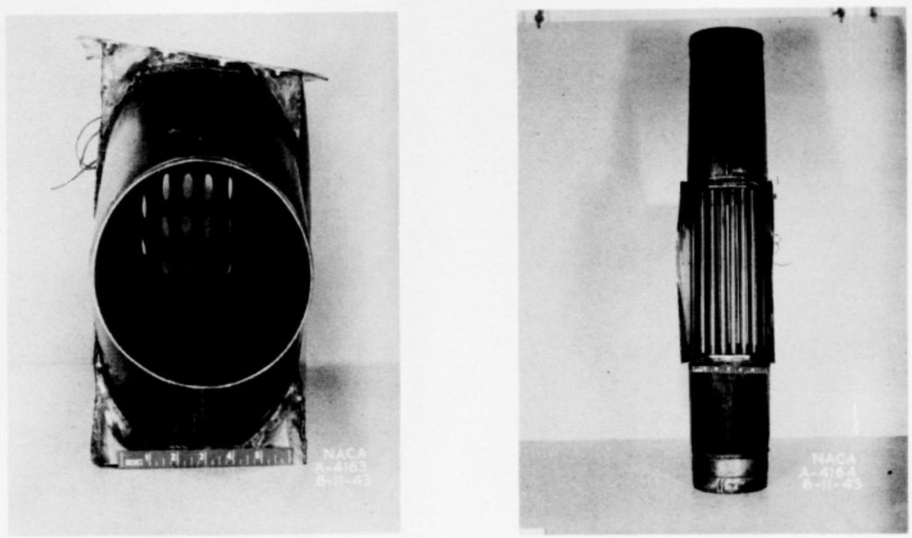

Figure 6.- Heat exchanger 2 as altered for installation in the B-17F airplane. Weight as shown, 39.6 pounds.

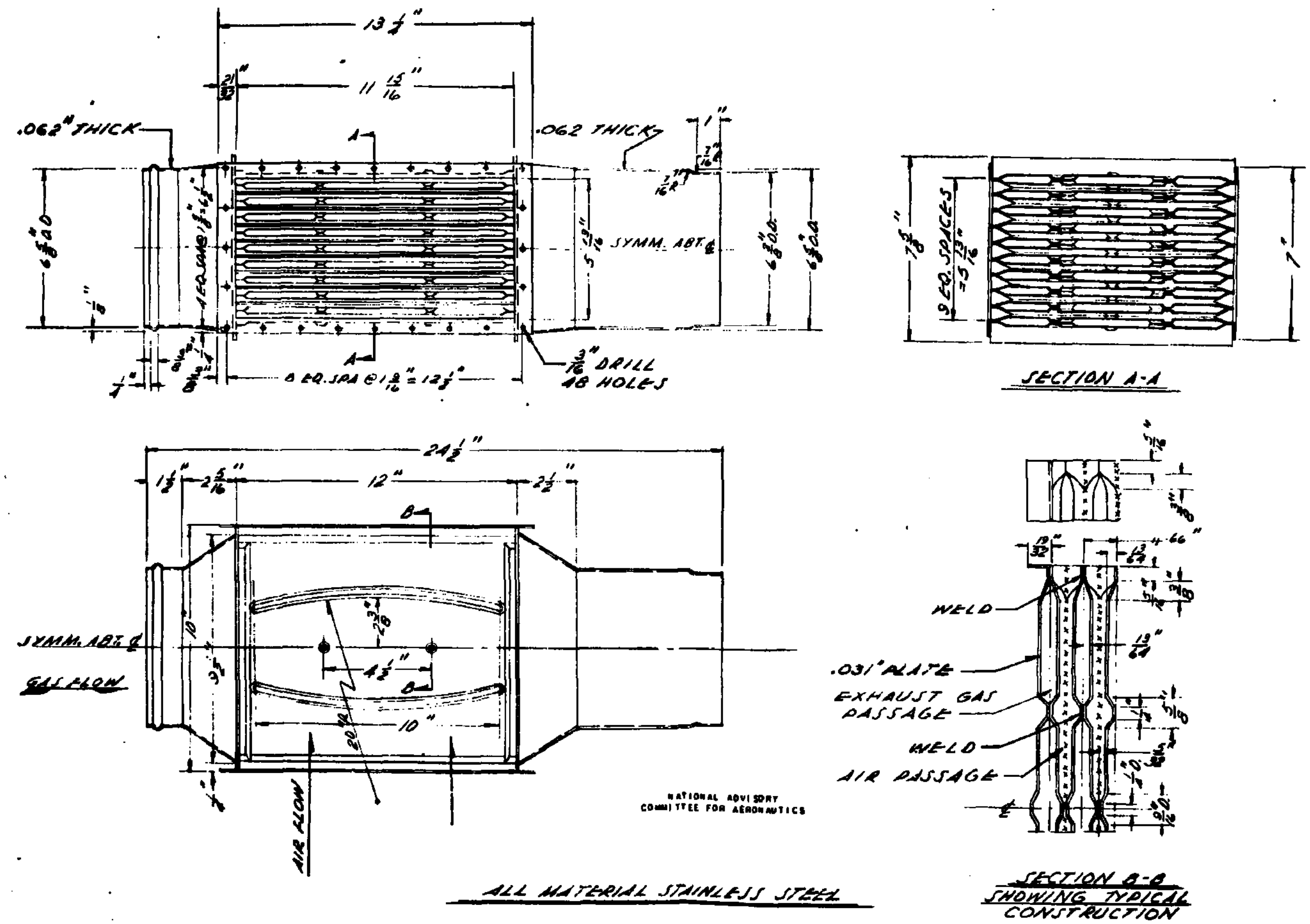

FIGURE 7. - HEAT EXCHANGER 3, PLATE TYPE, TESTED IN NACELLE 4 OF THE B-17F AIRPLANE

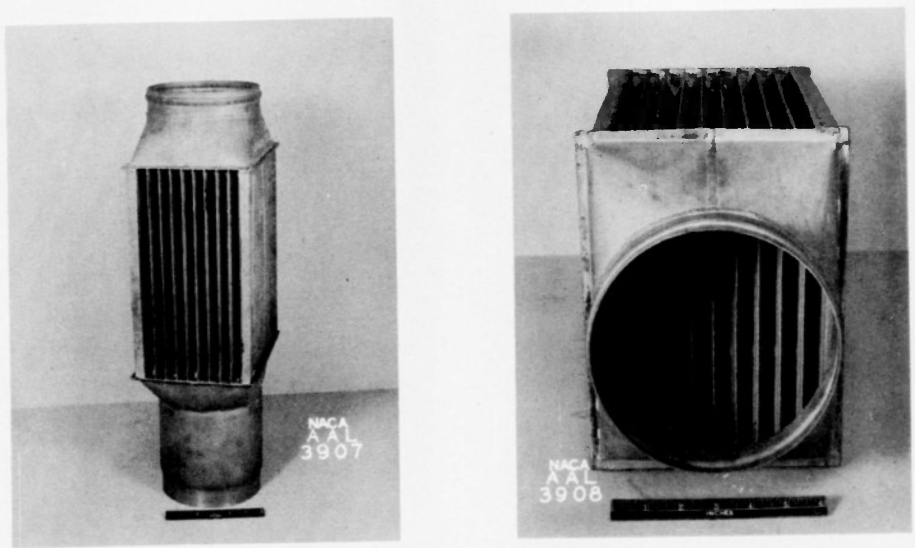

Figure 8. Heat exchanger 3 as installed in the B-17F airplane. Weight as shown, 29.0 pounds.

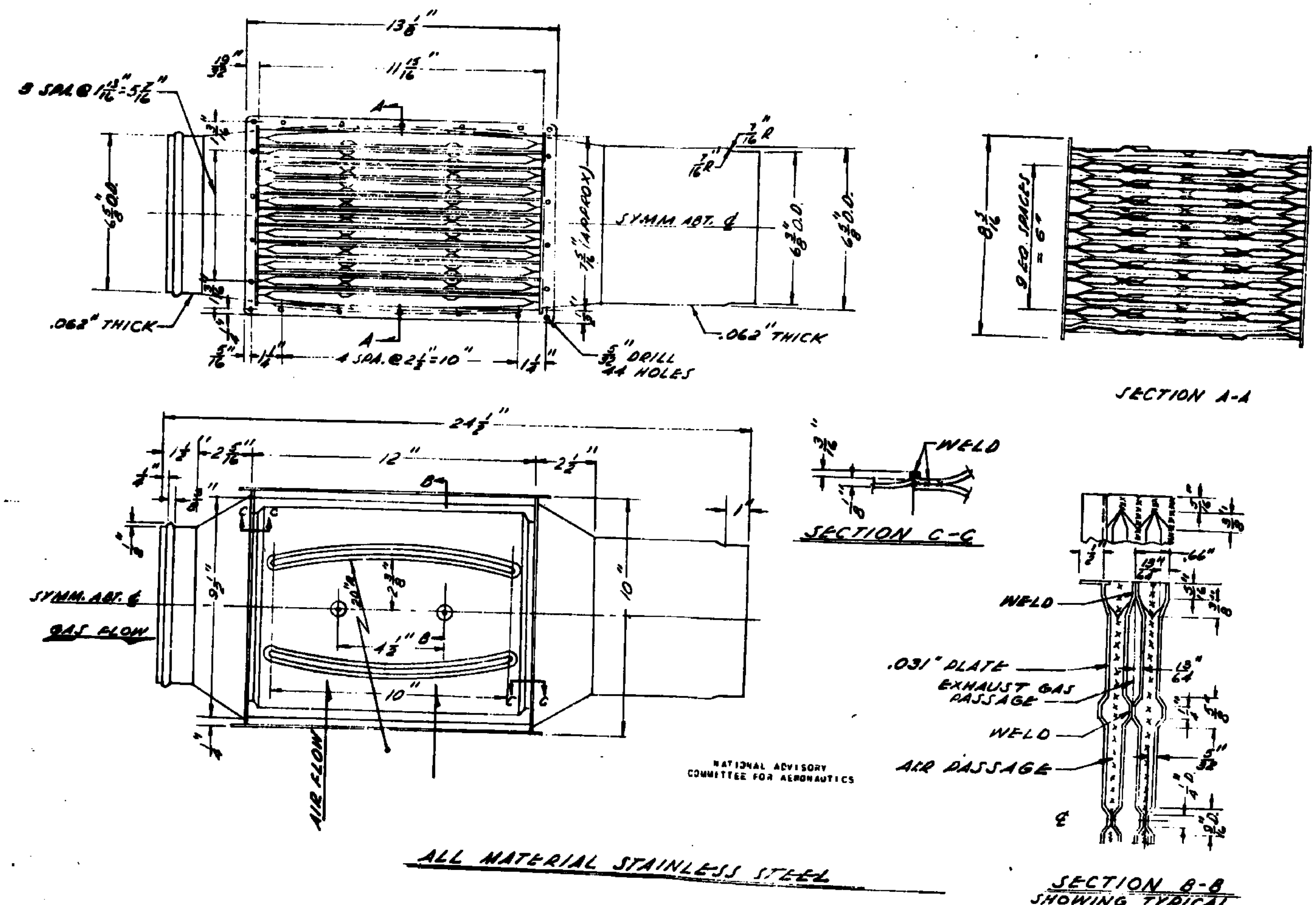

FIGURE 9. - HEAT EXCHANGER 4, PLATE TYPE, TESTED IN NACELLE 4 OF THE B-17F AIRPLANE

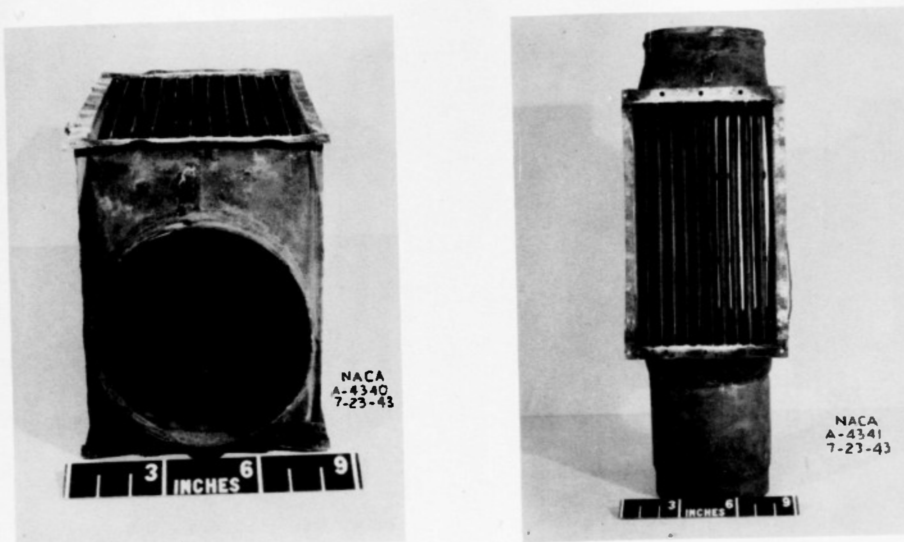

Figure 10.- Heat exchanger 4 as installed in the B-17F airplane. Weight as shown, 31.4 pounds.

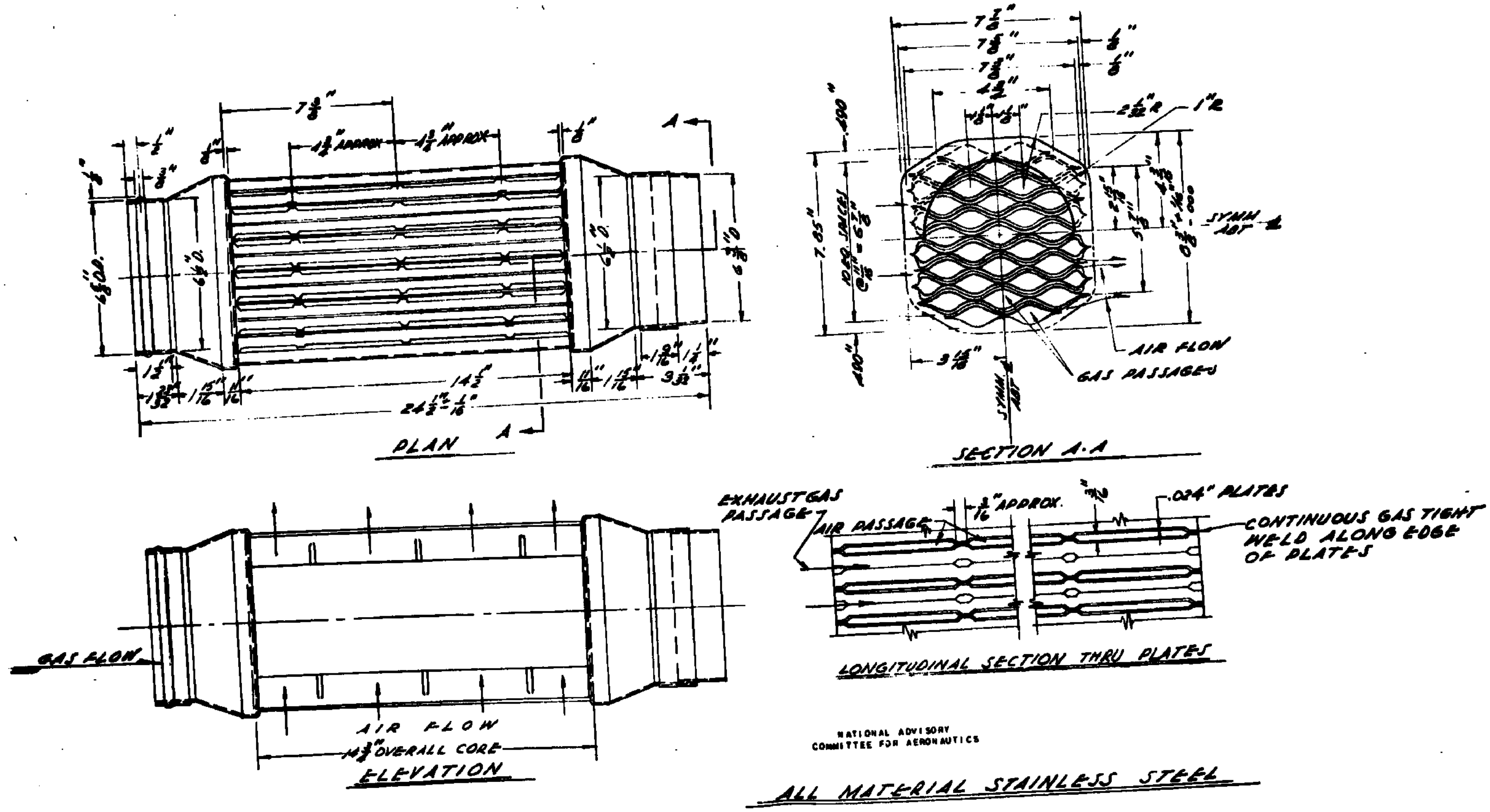

FIGURE 11.- HEAT EXCHANGER 5, PLATE TYPE, TESTED IN NACELLE 4 OF THE B-17F AIRPLANE

Figure 12.- Heat exchanger 5. Air inlet and outlet openings were slightly enlarged when installed in the B-17F airplane. Weight as shown, 33.0 pounds.

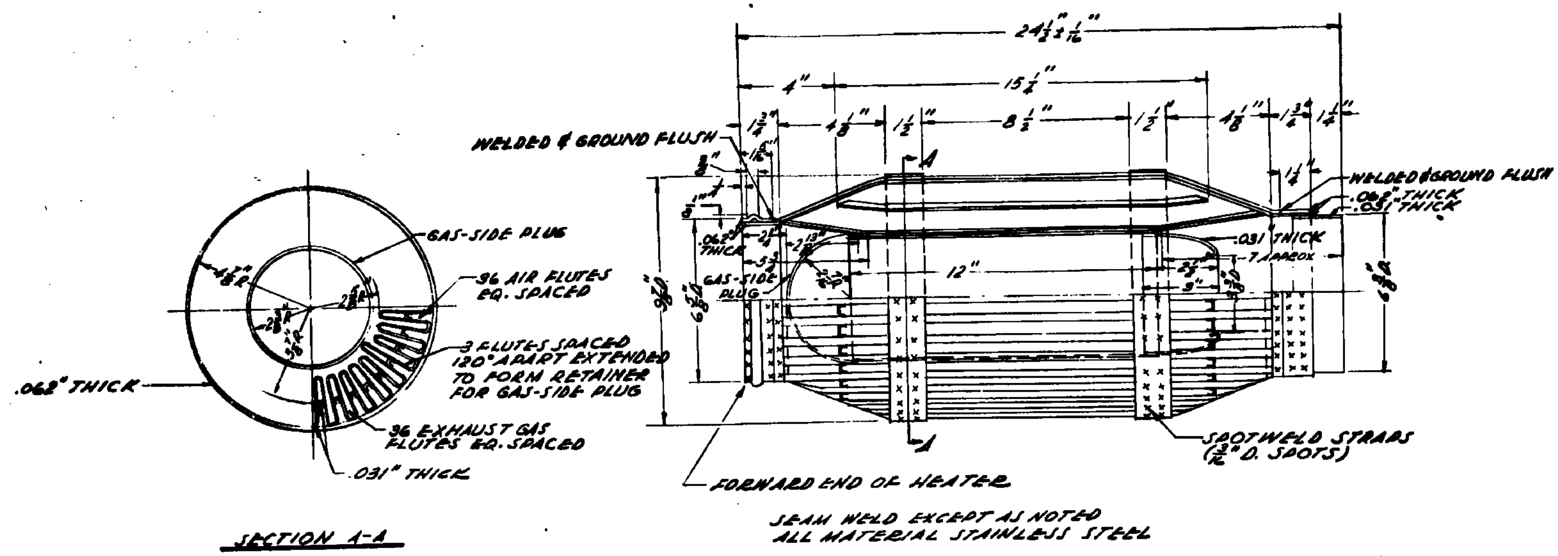

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FIGURE 13. - HEAT EXCHANGER 6, FLUTE TYPE, TESTED IN NACELLE 1 OF THE B-17F AIRPLANE

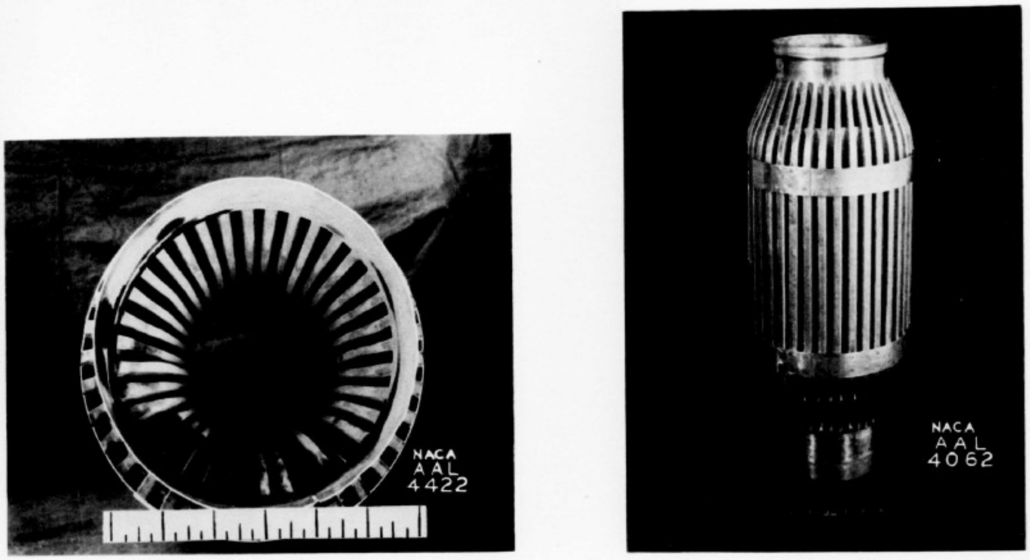


Figure 14.- Heat exchanger 6 as installed in the B-17F airplane. Weight as shown, 34.3 pounds.

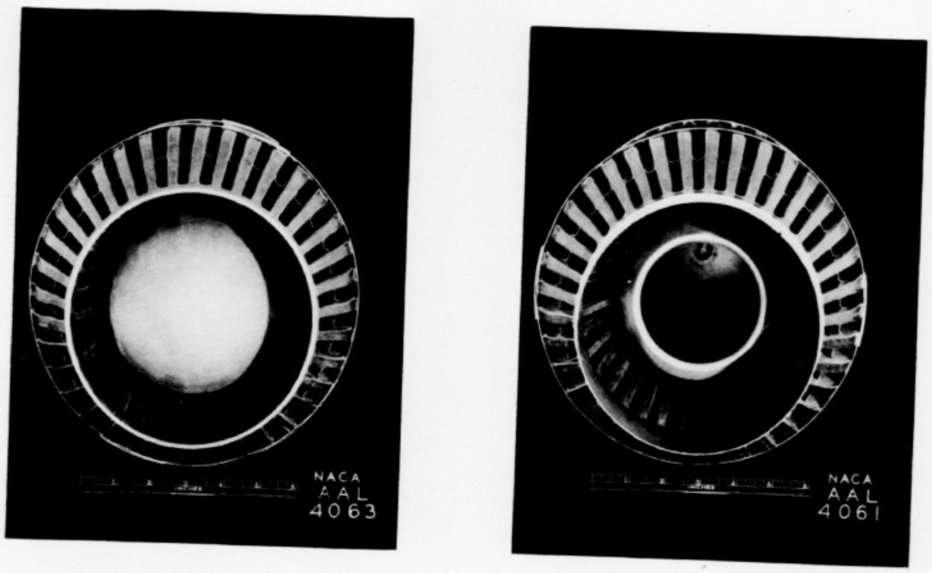
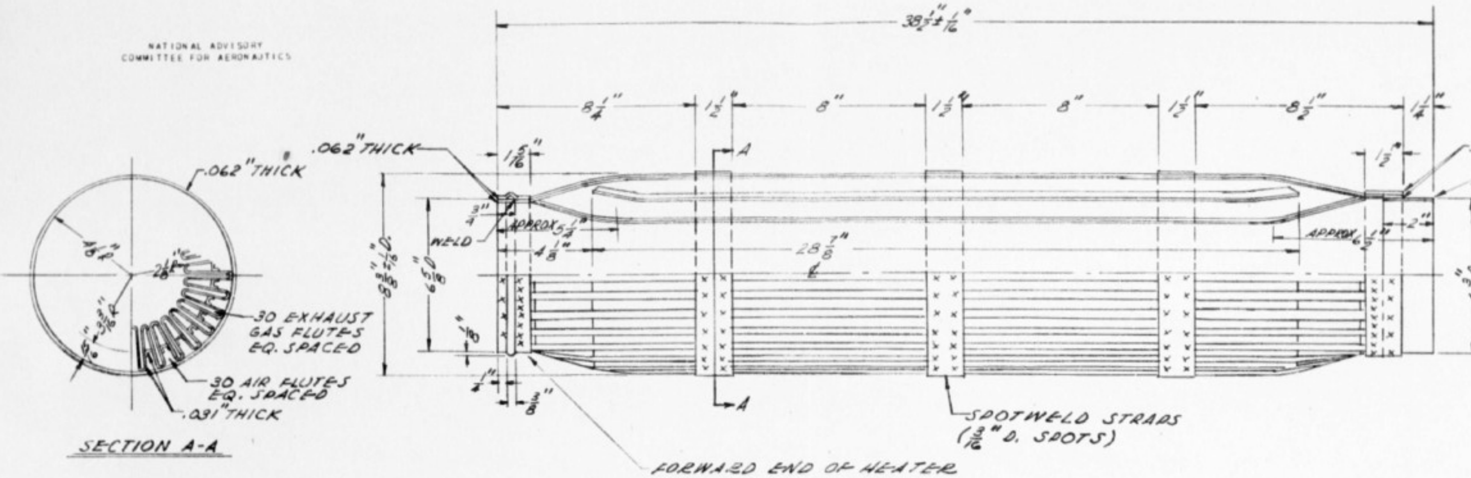


Figure 15.- Front and rear views of plug in the exhaust-gas side of heat exchanger 6 tested on the B-17F airplane. Weight as shown, 36.5 pounds.



SEAM WELD EXCEPT AS NOTED
ALL MATERIAL STAINLESS STEEL

FIGURE 16.- HEAT EXCHANGER 7, FLUTE TYPE, TESTED IN NACELLE 3 OF THE B-17F AIRPLANE

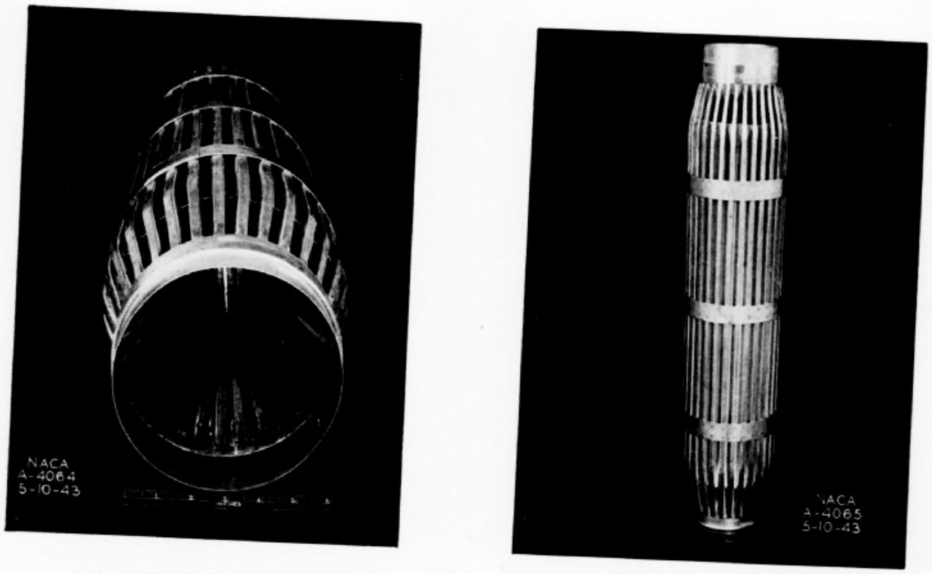


Figure 17.- Heat exchanger 7 as installed in the B-17F airplane. Weight as shown, 51.3 pounds.

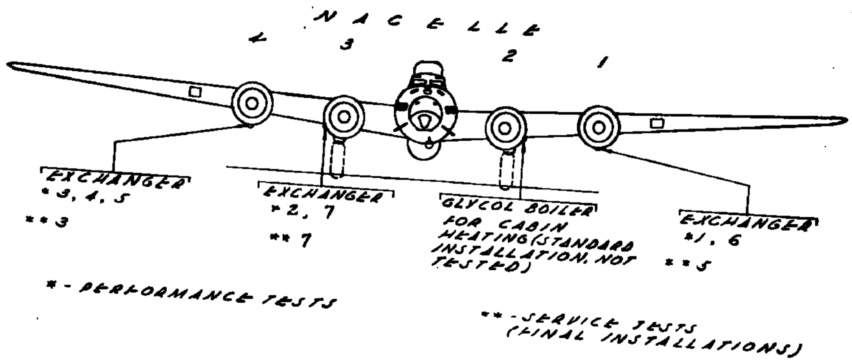


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FIGURE 18.- LOCATION OF HEAT EXCHANGERS INSTALLED IN THE B-17F AIRPLANE FOR THE PERFORMANCE AND SERVICE TESTS.

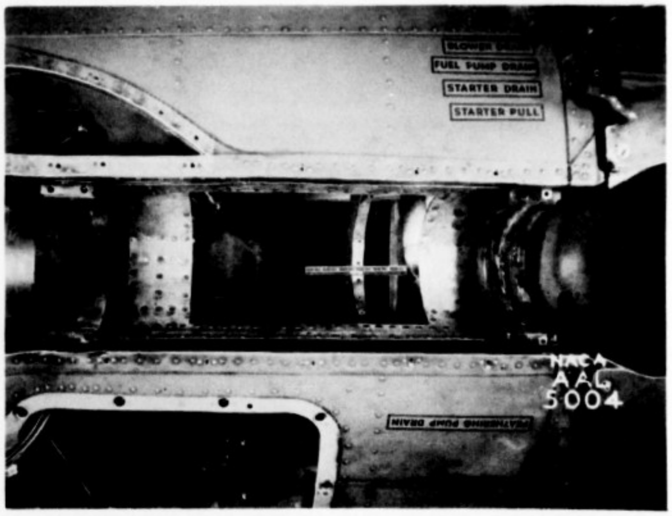

Figure 19.- Nacelle 1 exhaust shroud as altered for heat exchanger 1 installation. B-17F airplane.

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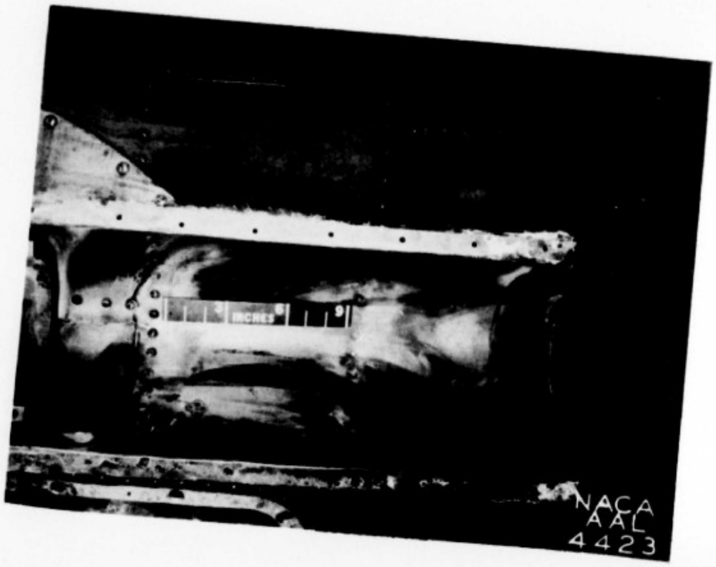

Figure 20.- Nacelle 1 exhaust shroud as altered for heat exchanger 6 installation. B-17F airplane.

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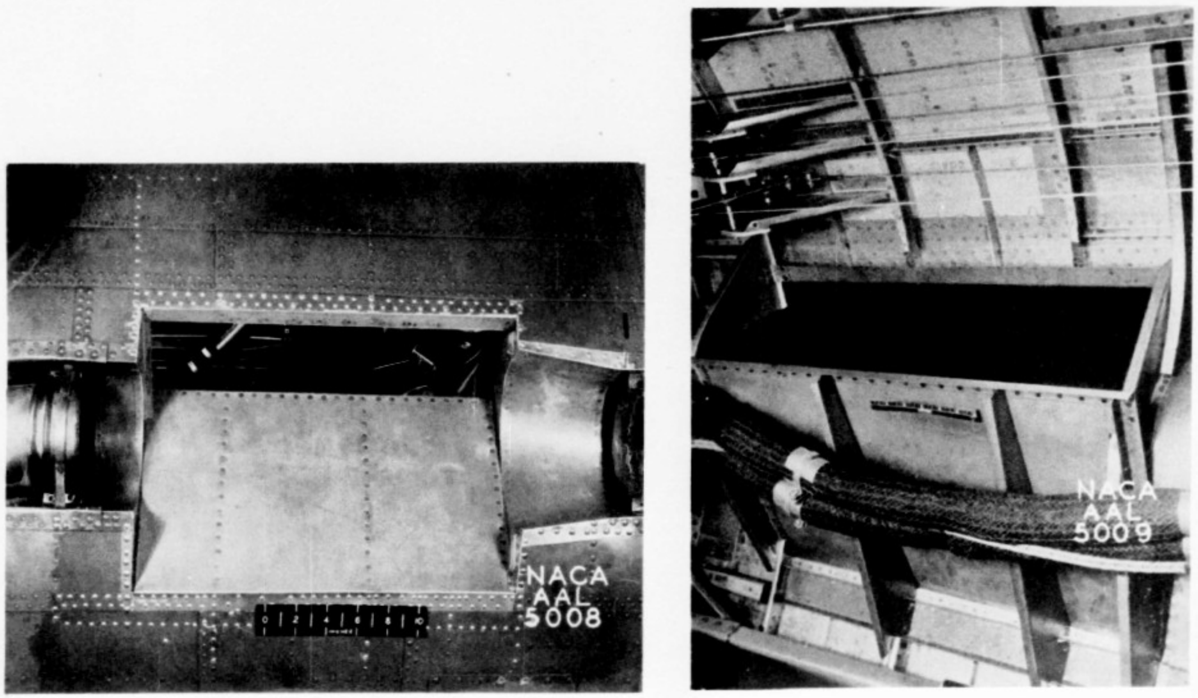

Figure 21. - Nacelle 3 exhaust shroud as altered for heat exchanger 2 installation. B-17F Airplane.

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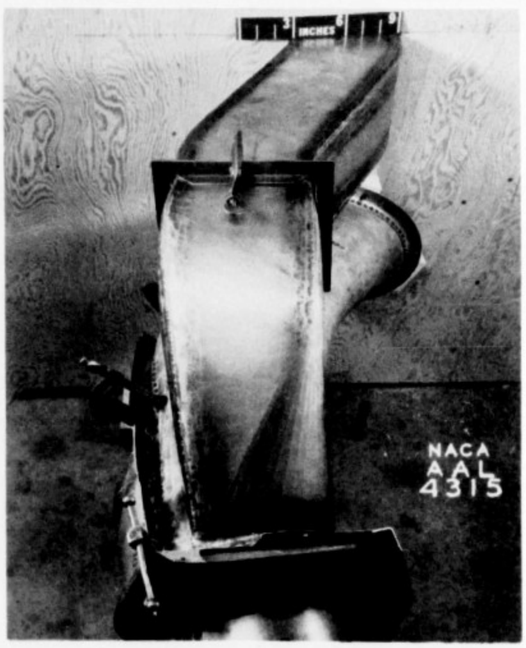


Figure 22.- Mock-up of heated-air outlet for heat exchanger 7 installation in nacelle 3, views looking outboard and aft. B-17F airplane.

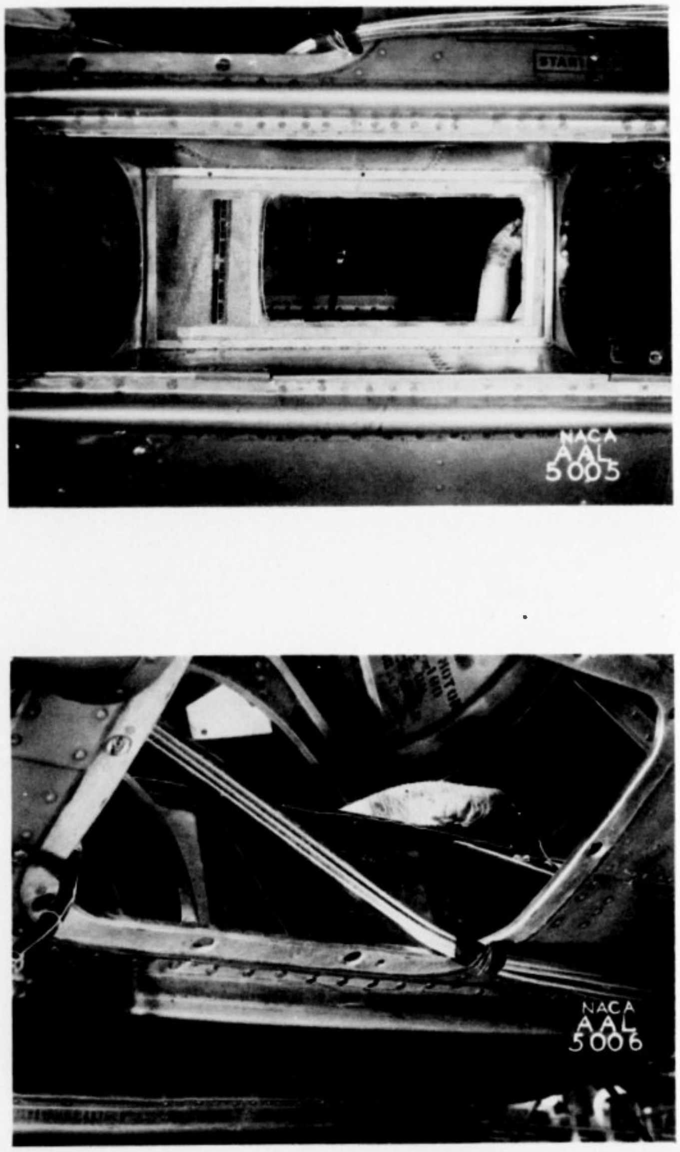


Figure 23.- Nacelle 4 exhaust shroud as altered for installation of heat exchangers 3, 4, and 5. B-17F airplane.

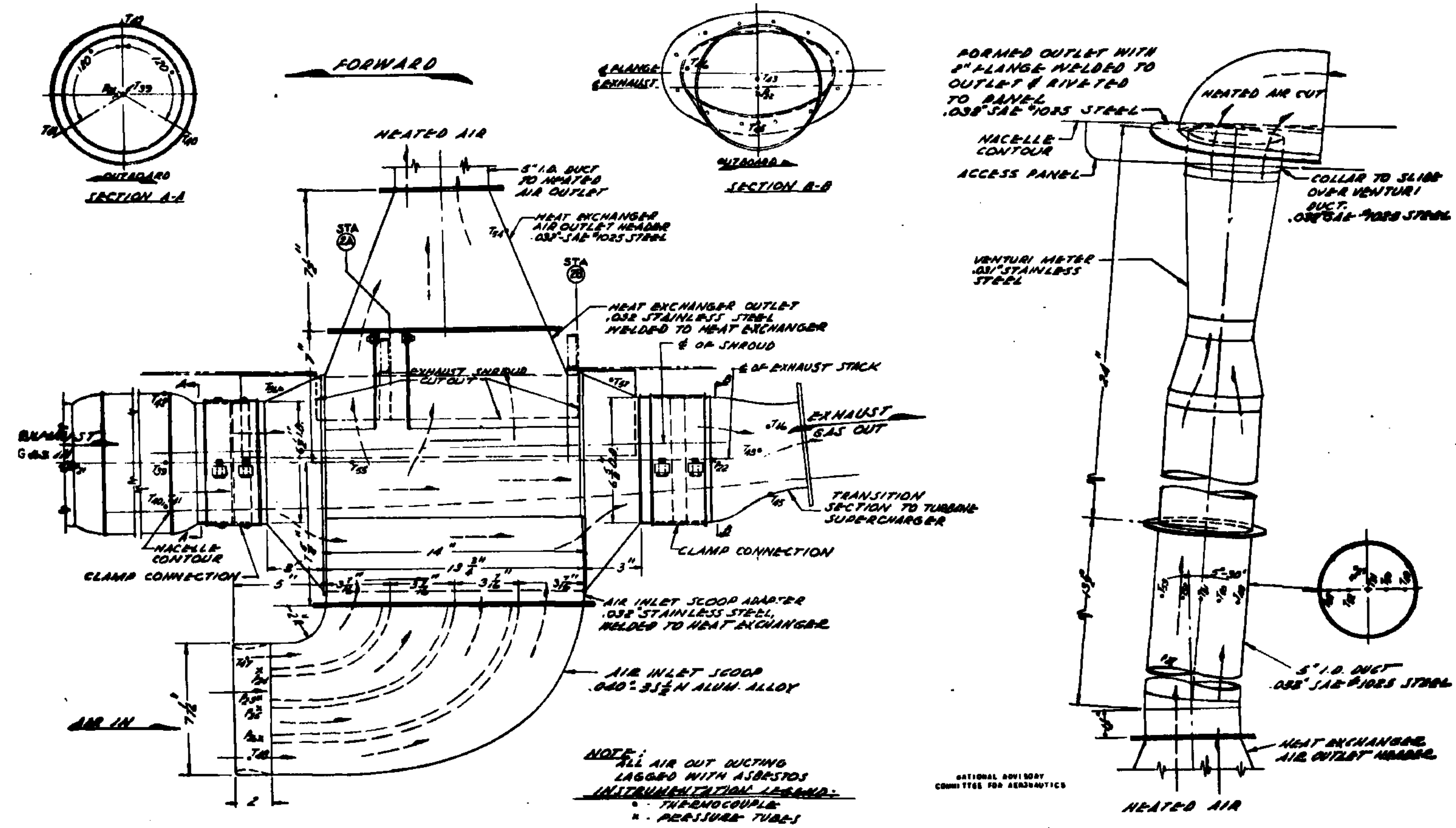


FIGURE 24.- HEAT EXCHANGER I INSTALLATION IN NACELLE I. SIDE VIEW, B-17F AIRPLANE.

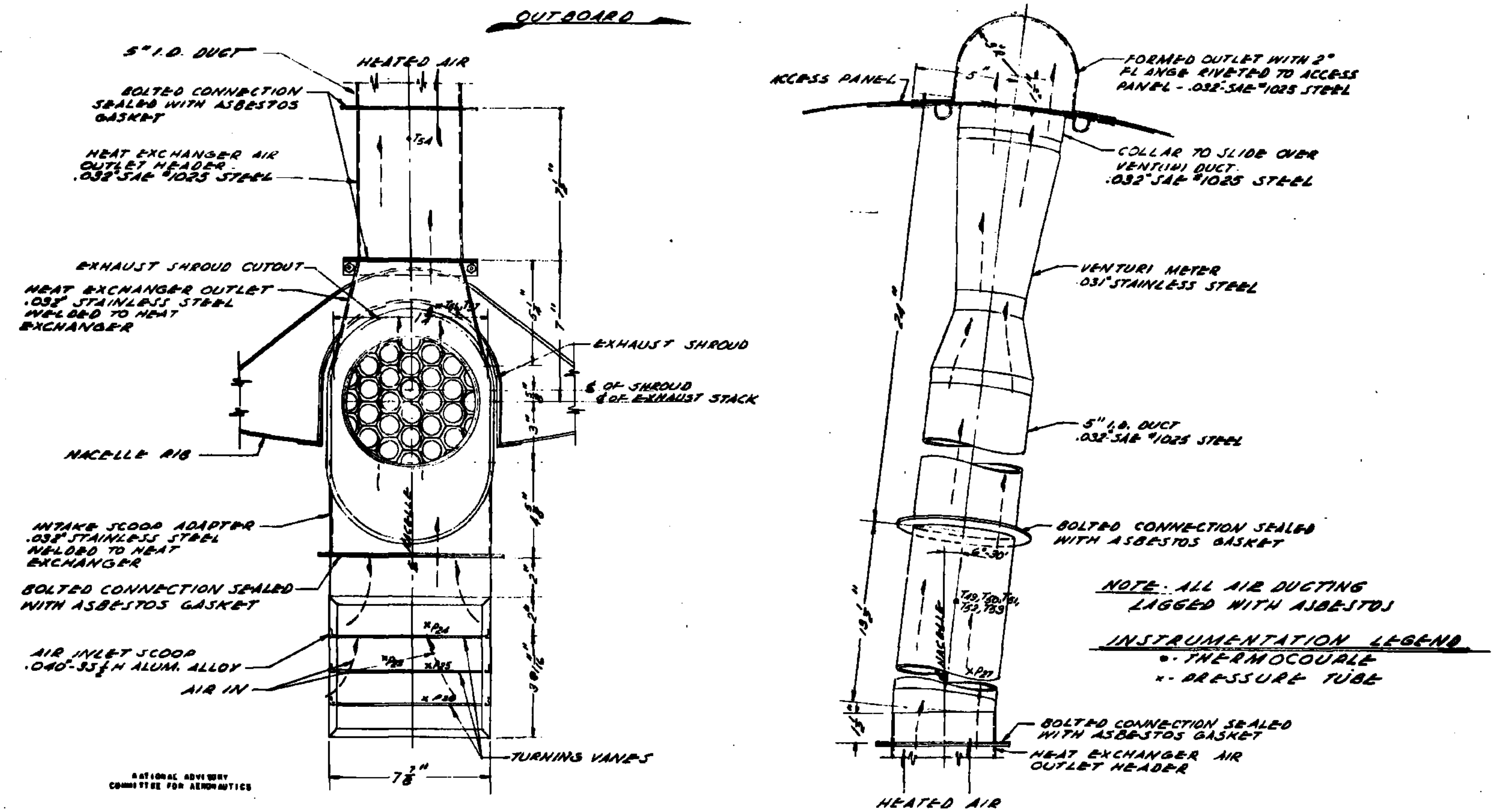


FIGURE 25.- HEAT EXCHANGER 1 INSTALLATION IN NACELLE 1, FRONT VIEW, B-17F AIRPLANE.

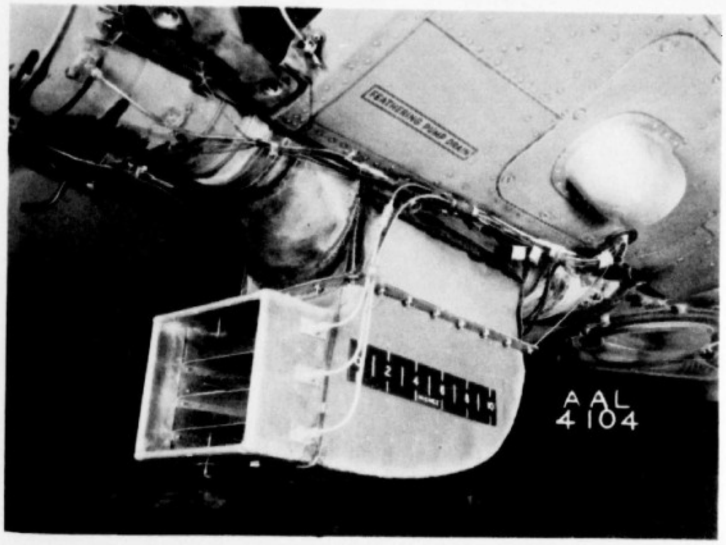


Figure 26.- Heat exchanger 1 installation in nacelle 1, ready for flight, B-17F airplane.

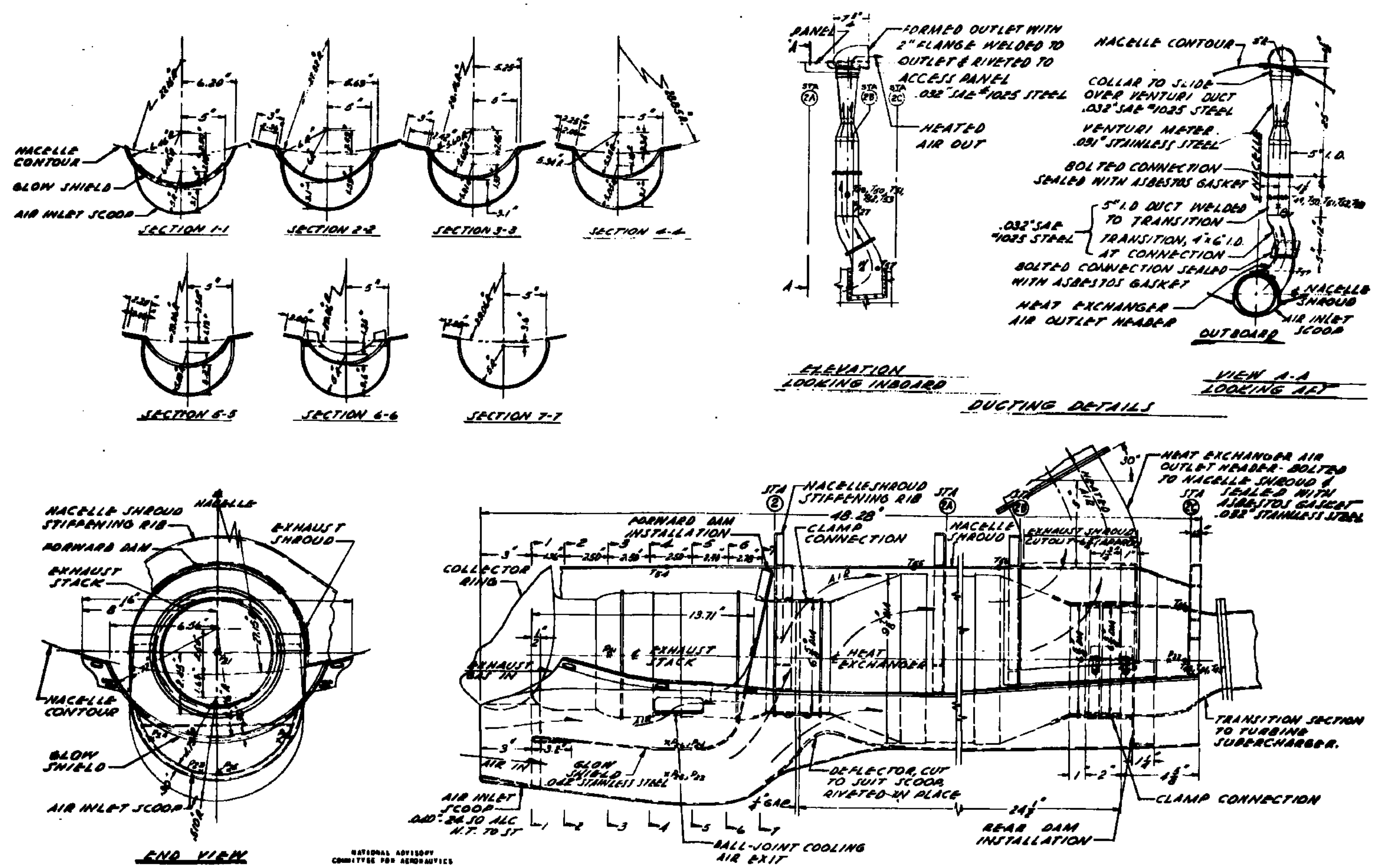


FIGURE 27. - HEAT EXCHANGER 6, INSTALLATION IN NACELLE 1, SIDE AND END VIEWS, AND DUCTING TO HEATER AIR OUTLET. B-17F AIRPLANE

NOTE:
ALL AIR OUT DUCTING LAGGED WITH ASBESTOS

INSTRUMENTATION LEGEND
o - THERMOCOUPLE
x - PRESSURE HEAD

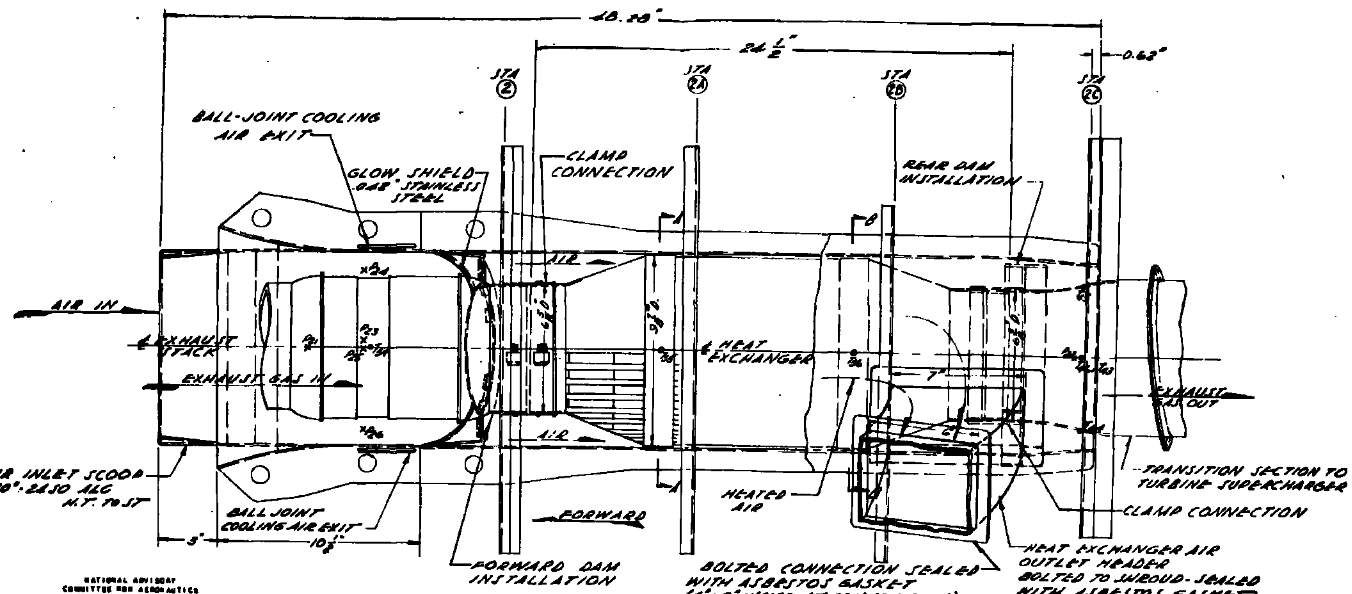
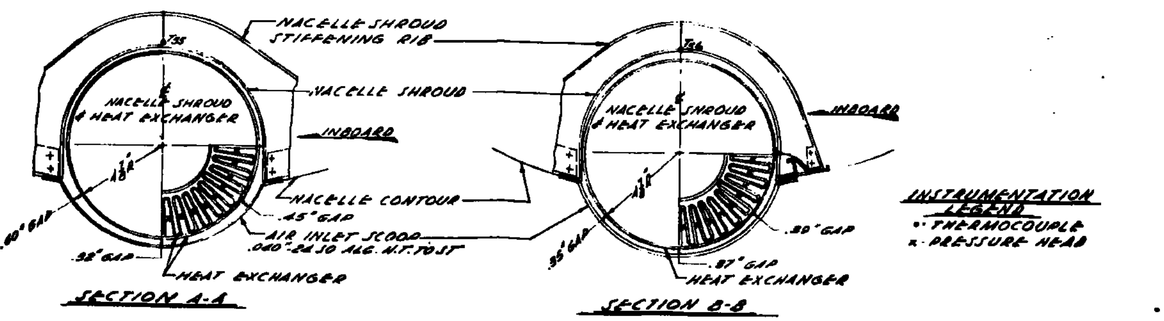


FIGURE 28.- HEAT EXCHANGER 6 INSTALLATION IN NACELLE 1, TOP VIEW, B-17F AIRPLANE.



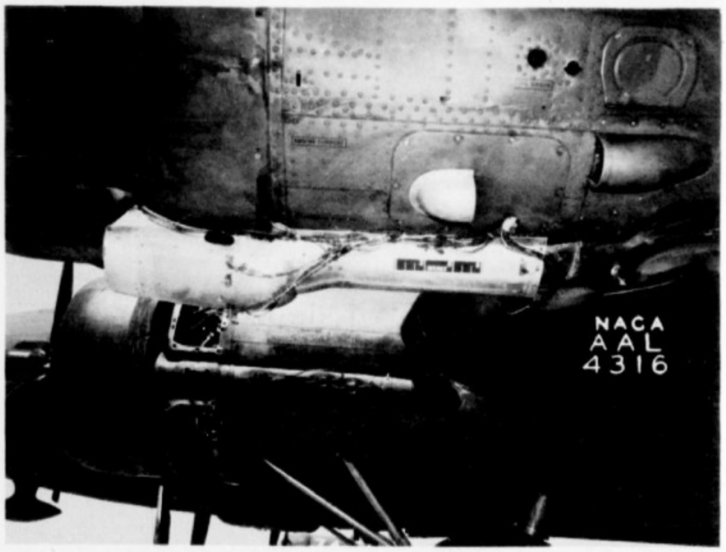


Figure 29.- Heat exchanger 6 installation in nacelle 1, ready for flight. B-17F airplane.

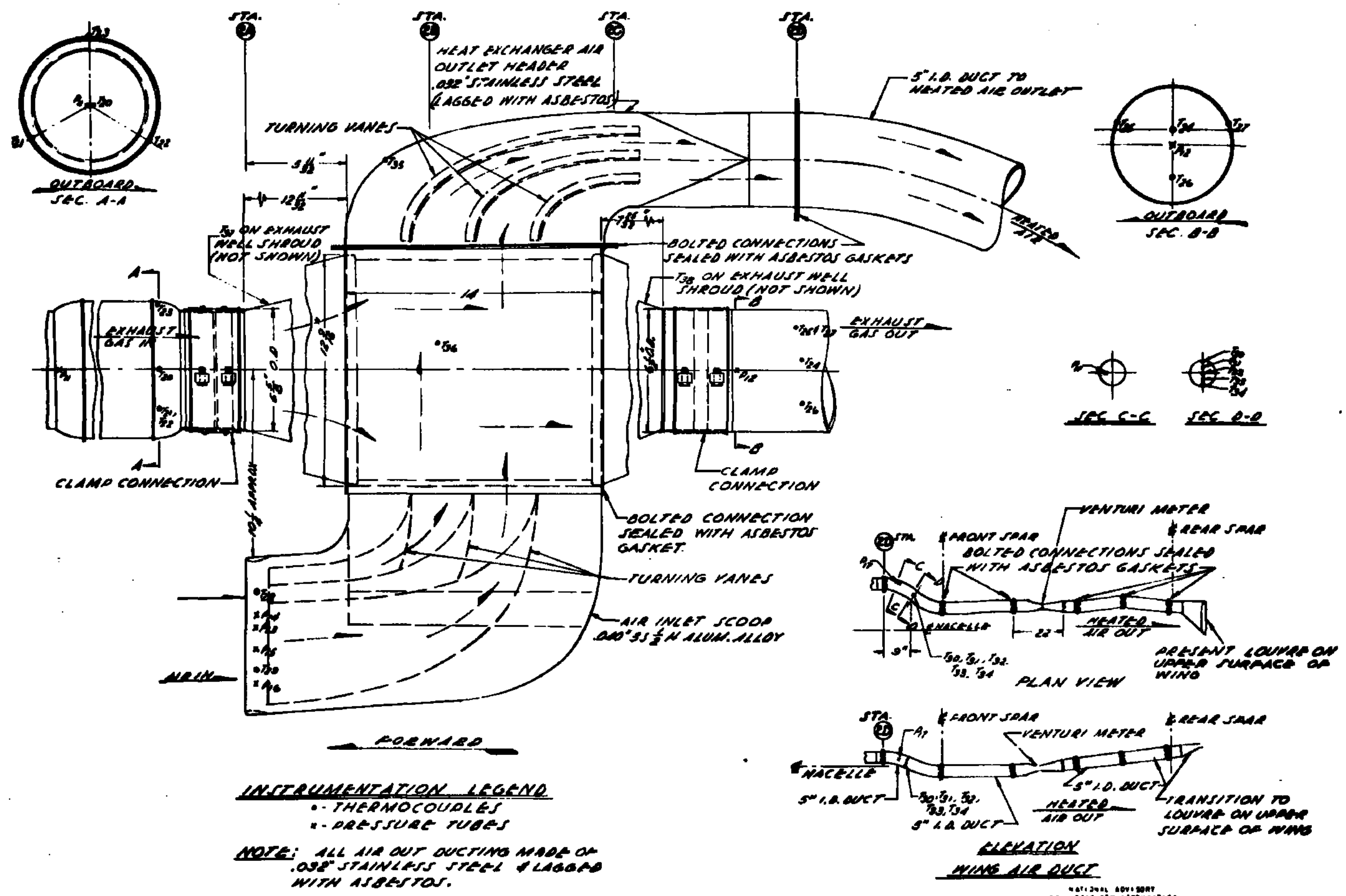


FIGURE 30.—HEAT EXCHANGER 2 INSTALLATION IN NACELLE 3, SIDE VIEW, AND DUCTING TO HEATED AIR OUTLET. B-17F AIRPLANE.

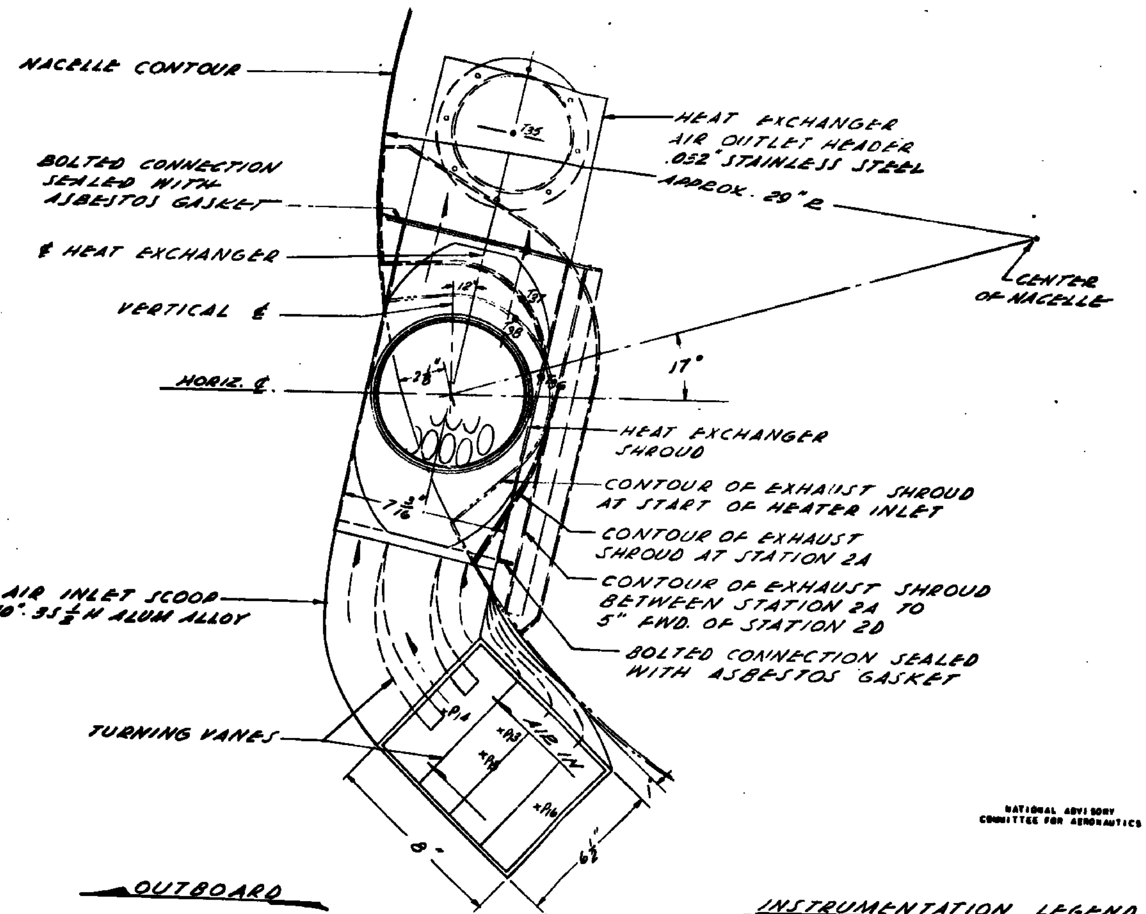


FIGURE 31.- HEAT EXCHANGER 2 INSTALLATION IN NACELLE 3, FRONT VIEW, B-17F AIRPLANE.

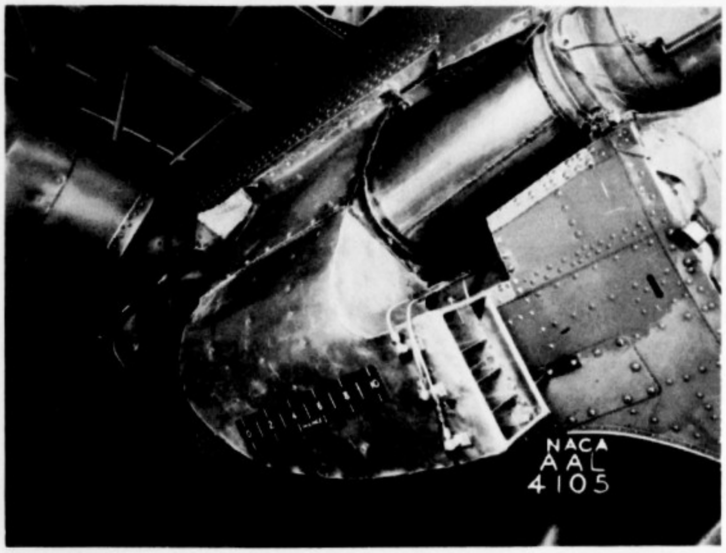
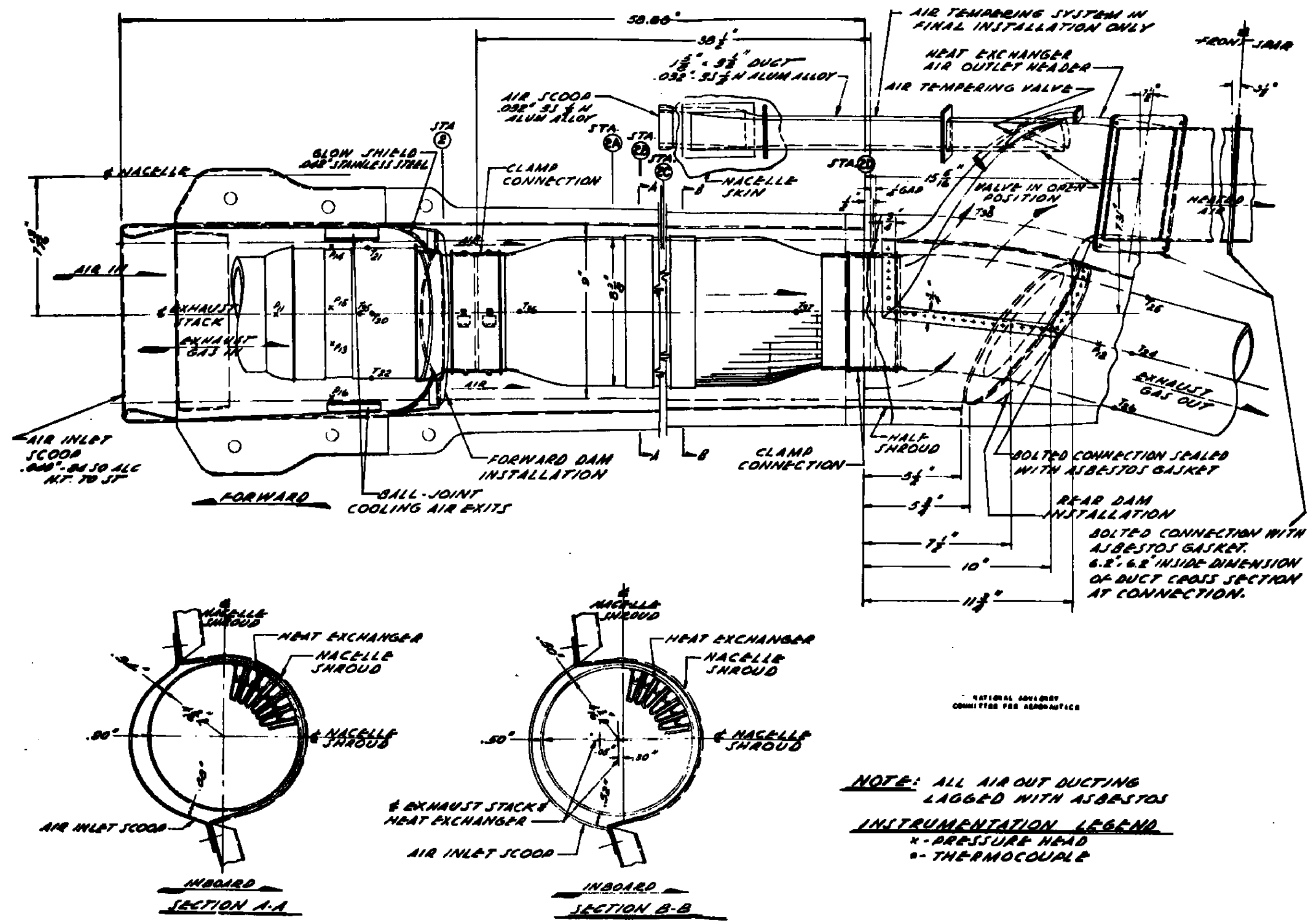


Figure 32.- Heat exchanger 2 installation in nacelle 3, ready for flight.. B-17F airplane.



NOTE: ALL AIR OUT DUCTING LAGGED WITH ASBESTOS

INSTRUMENTATION LEGEND
× - PRESSURE HEAD
• - THERMOCOUPLE

FIGURE 33.- HEAT EXCHANGER 7 INSTALLATION IN NACELLE 3, SIDE VIEW, B-17F AIRPLANE.

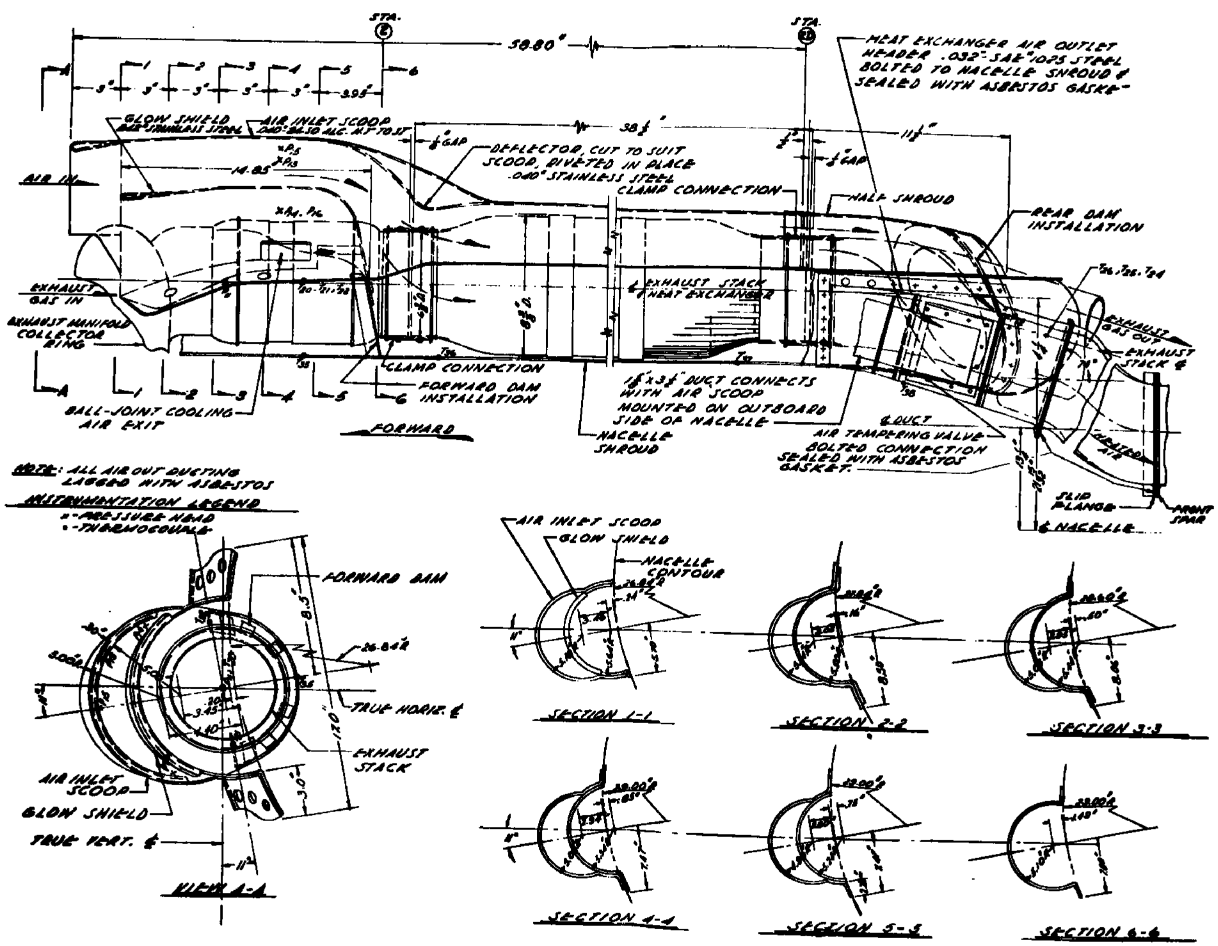


FIGURE 34.- HEAT EXCHANGER 7 INSTALLATION IN NACELLE 3, TOP AND FRONT VIEWS, B-17F AIRPLANE.

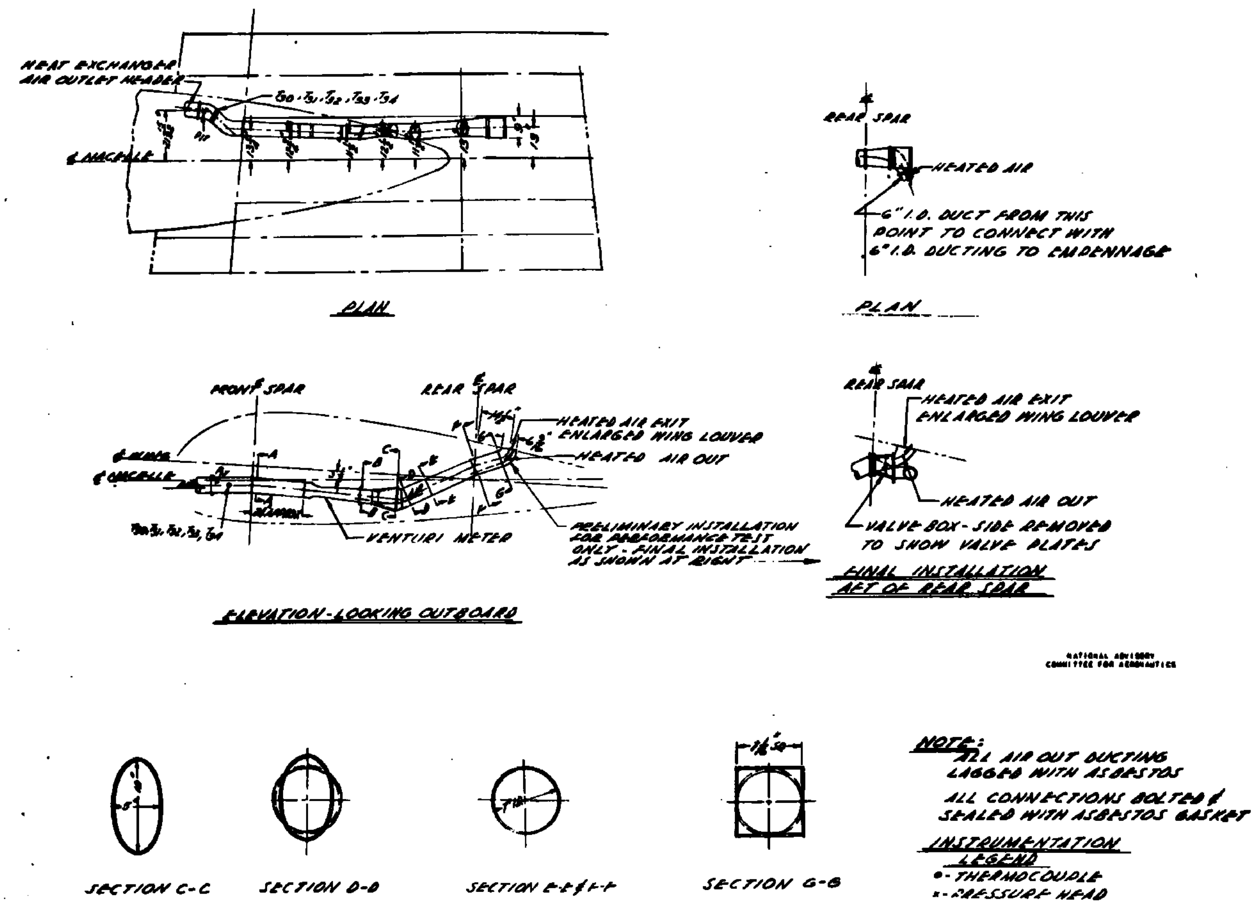


FIGURE 35.- HEAT EXCHANGER 7 INSTALLATION IN NACELLE 3. DUCTING TO HEATED AIR OUTLET, B-17F AIRPLANE.

Figure 36.- Heat exchanger 7 installation in nacelle 3, ready for flight. B-17F airplane.

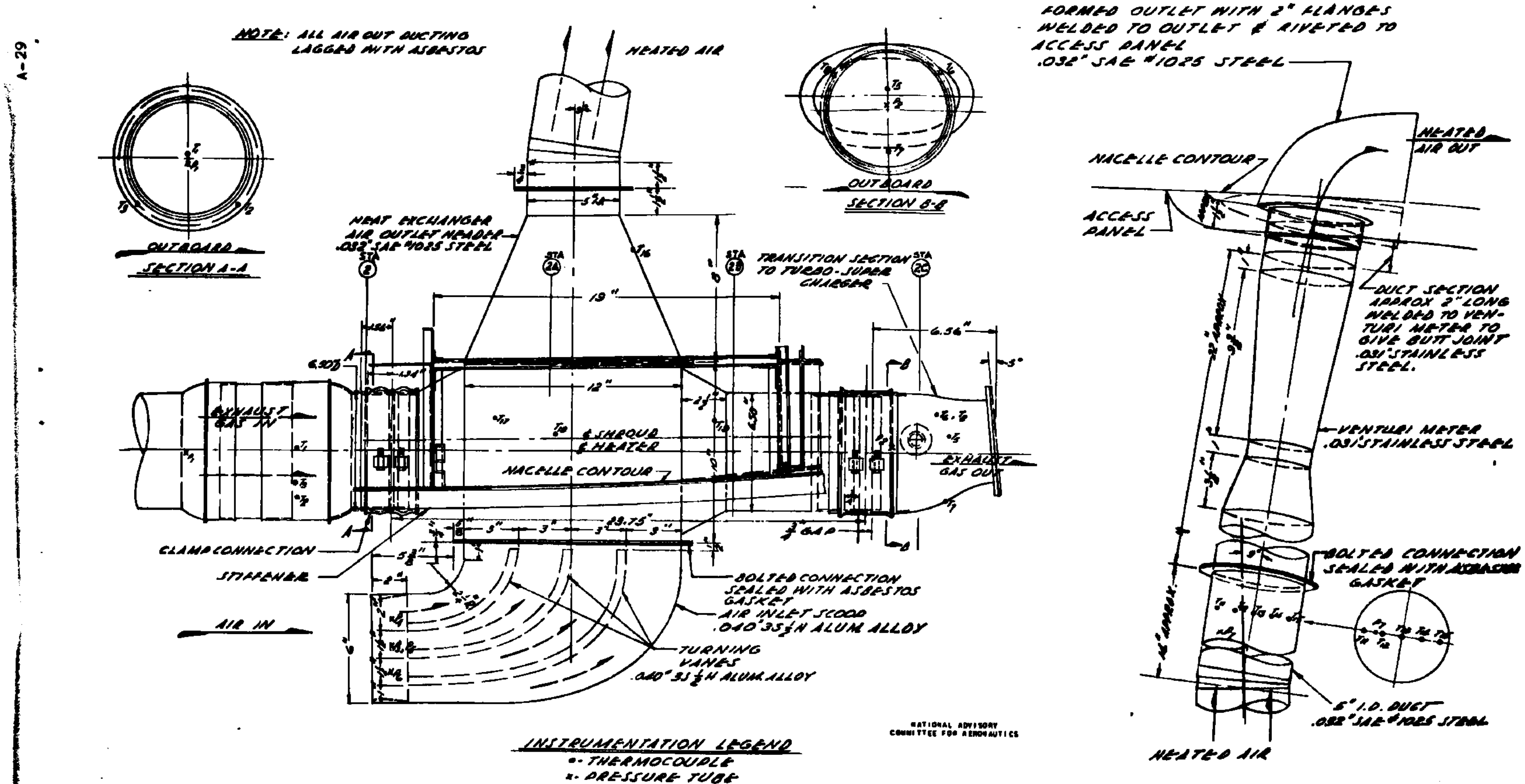


FIGURE 37.- HEAT EXCHANGER 3 INSTALLATION IN NACELLE 4, SIDE VIEW, B-17F AIRPLANE.

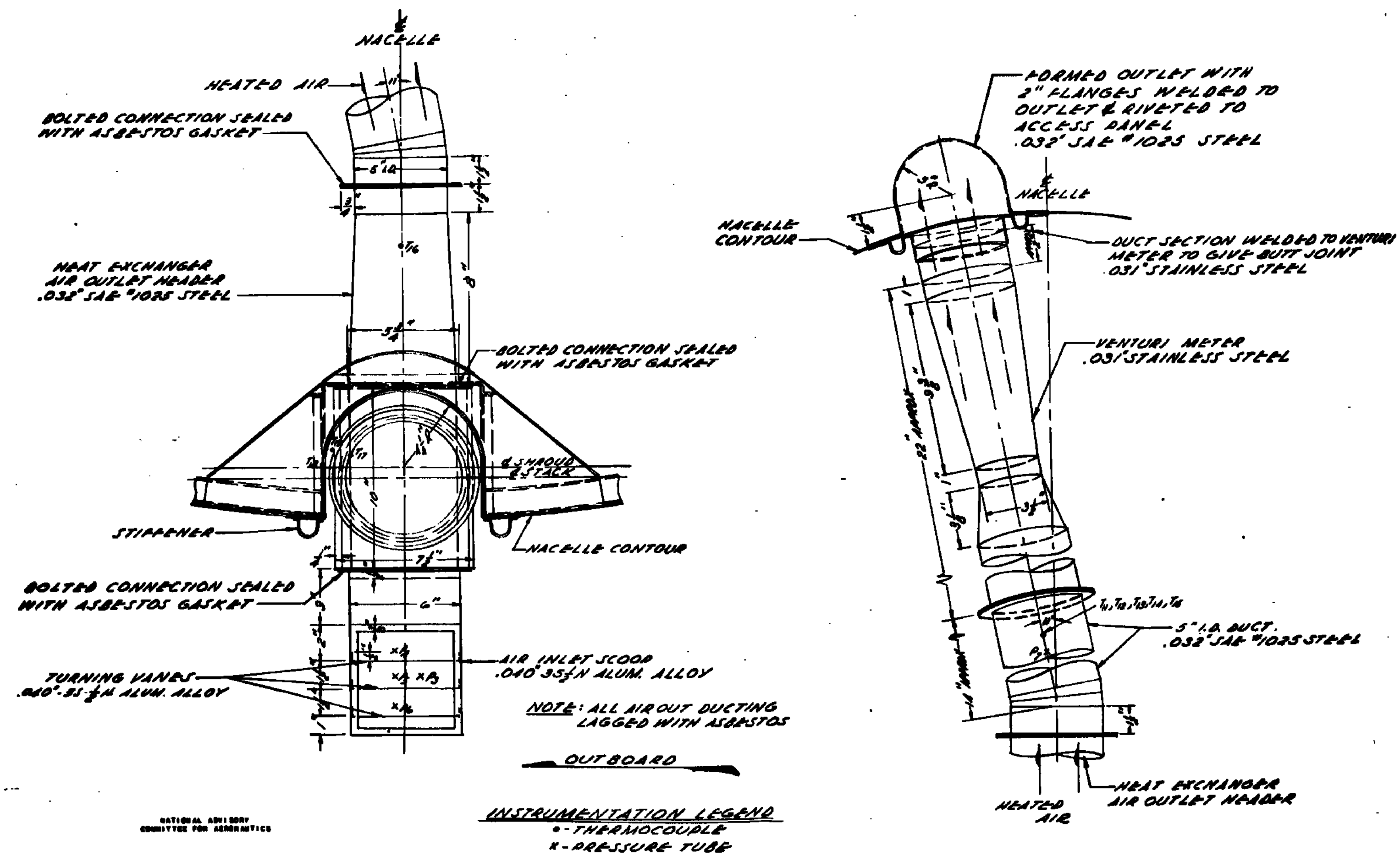


FIGURE 38.- HEAT EXCHANGER 3 INSTALLATION IN NACELLE 4, FRONT VIEW, B-17F AIRPLANE.

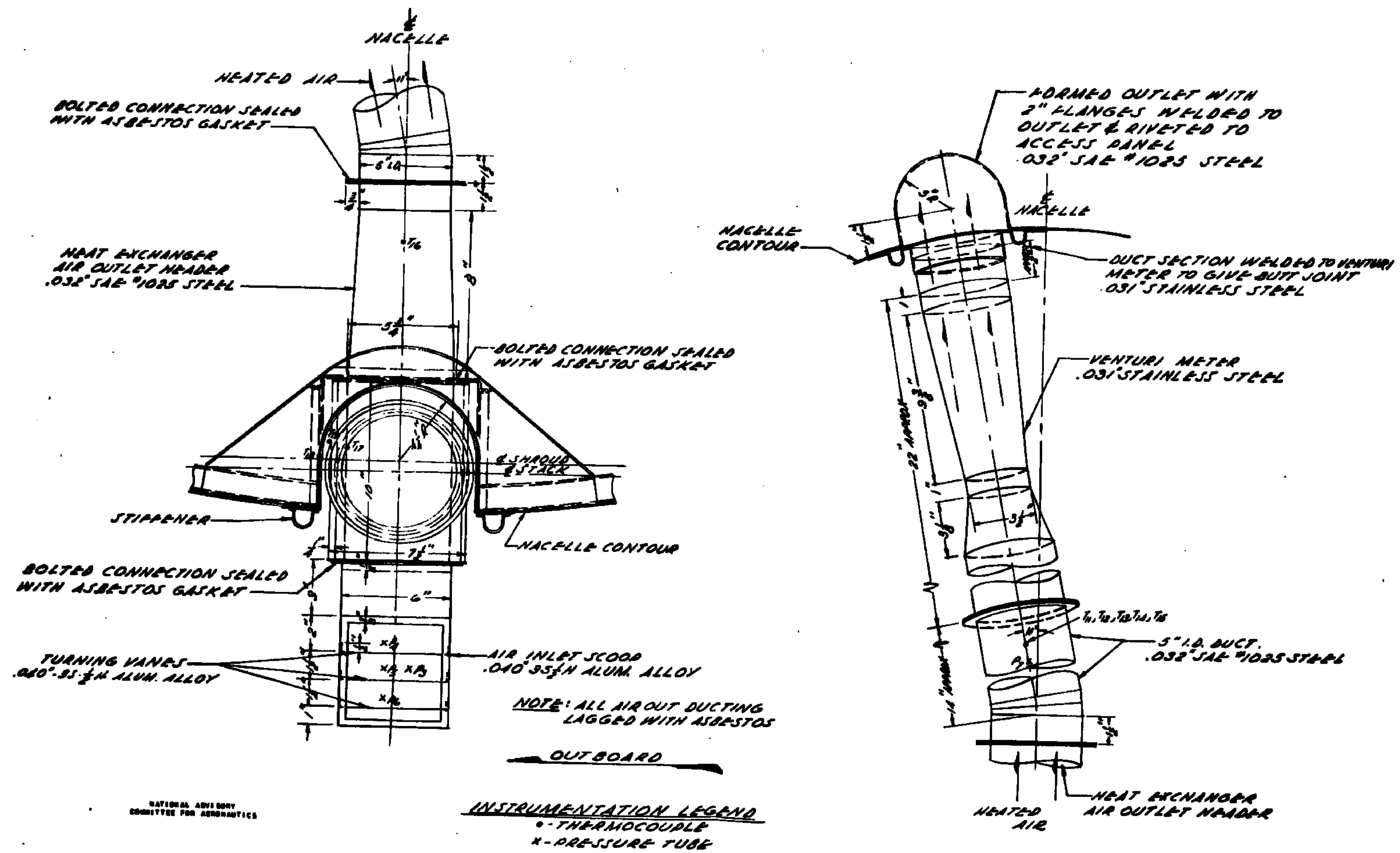


FIGURE 38.- HEAT EXCHANGER 3 INSTALLATION IN NACELLE 4, FRONT VIEW, B-17F AIRPLANE.

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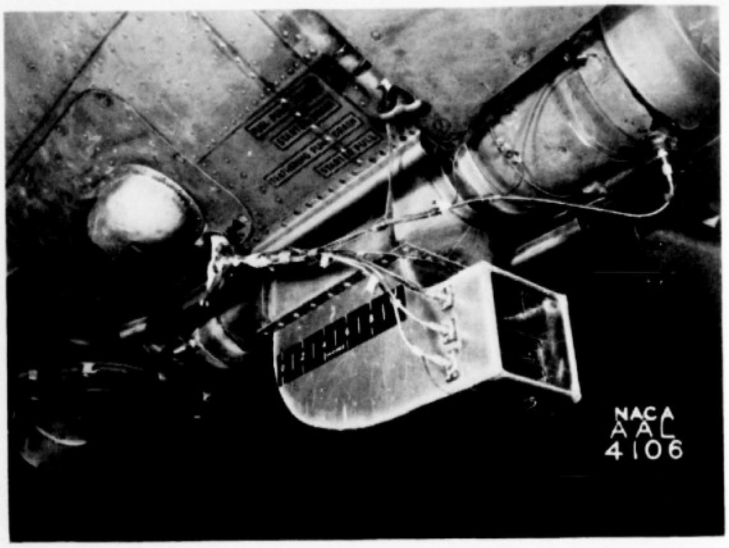

Figure 39.- Heat exchanger 3 installation in nacelle 4, ready for flight. B-17F airplane.

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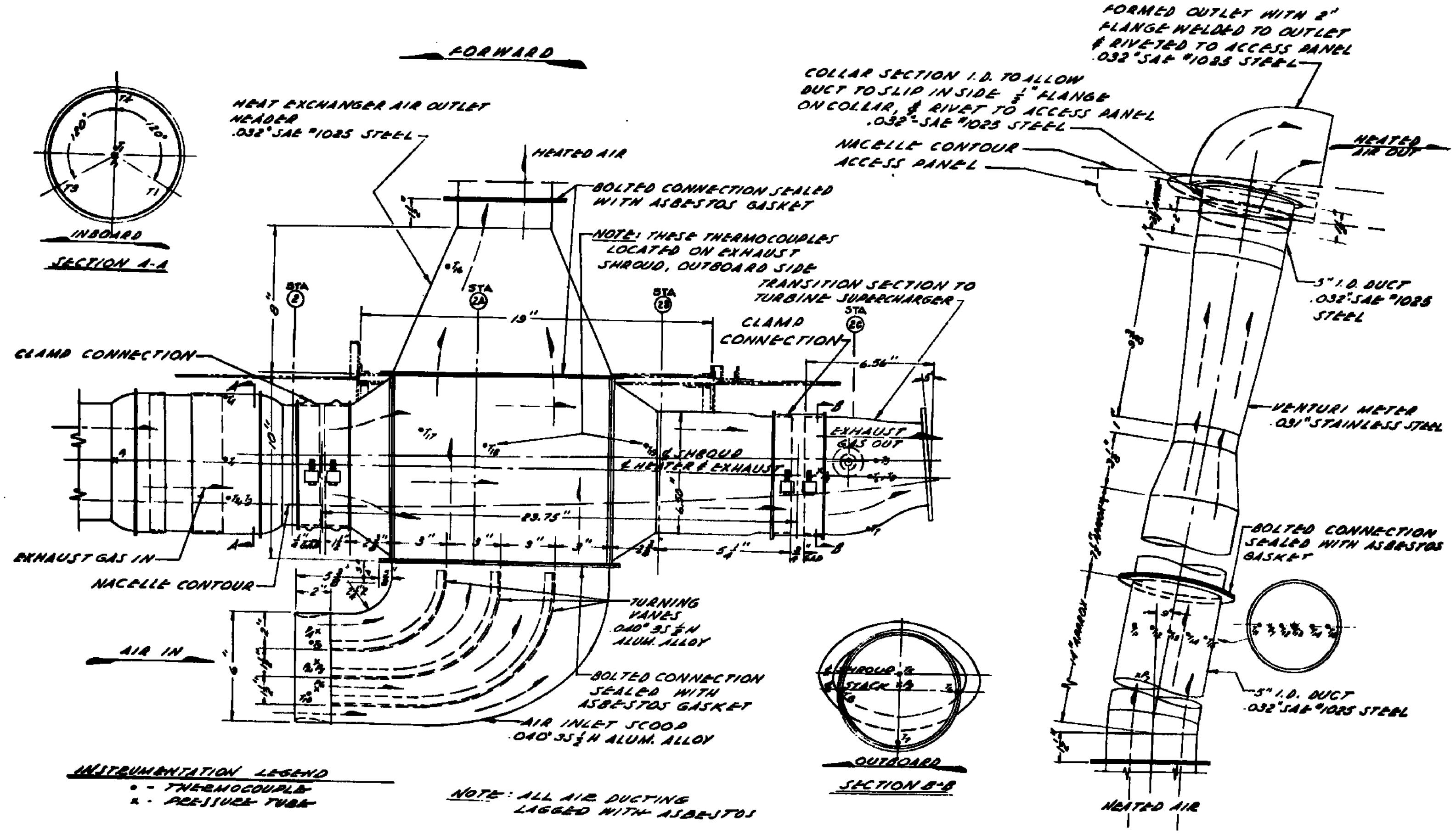

FIGURE 40.- HEAT EXCHANGER 4 INSTALLATION IN NACELLE 4, SIDE VIEW, B-17F AIRPLANE.

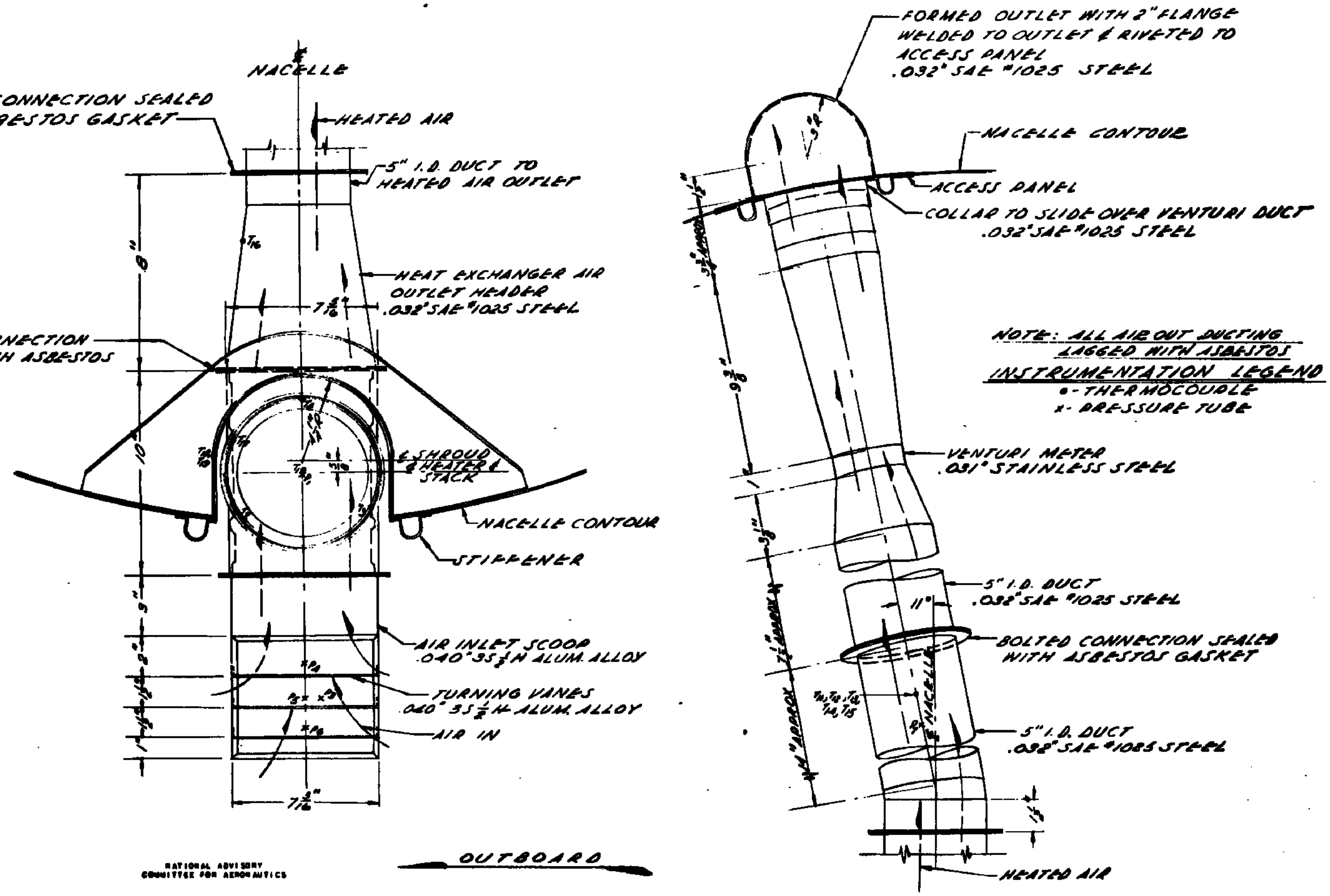

FIGURE 41.- HEAT EXCHANGER 4 INSTALLATION IN NACELLE 4, FRONT VIEW, B-17F AIRPLANE.

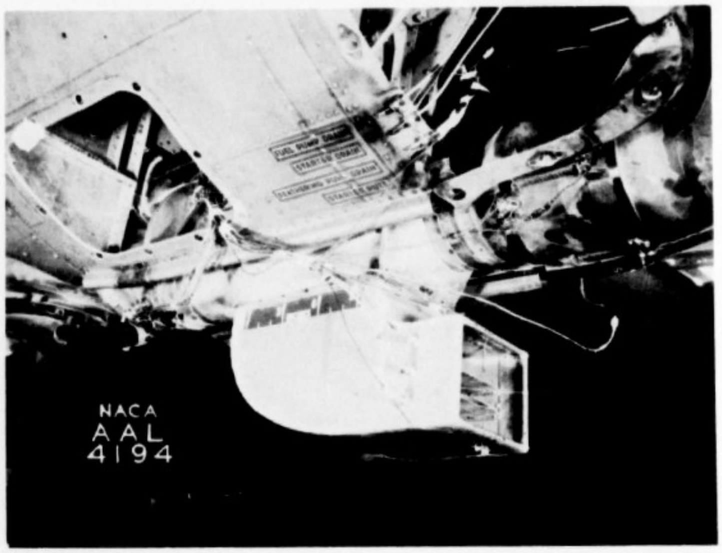

Figure 42.- Heat exchanger 4 installation in nacelle 4, ready for flight. B-17F airplane.

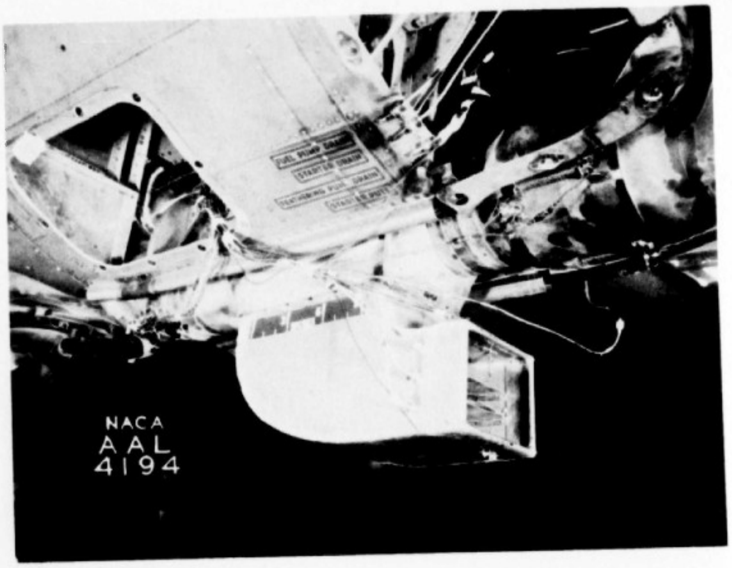

Figure 42.- Heat exchanger 4 installation in nacelle 4, ready for flight. B-17F airplane.

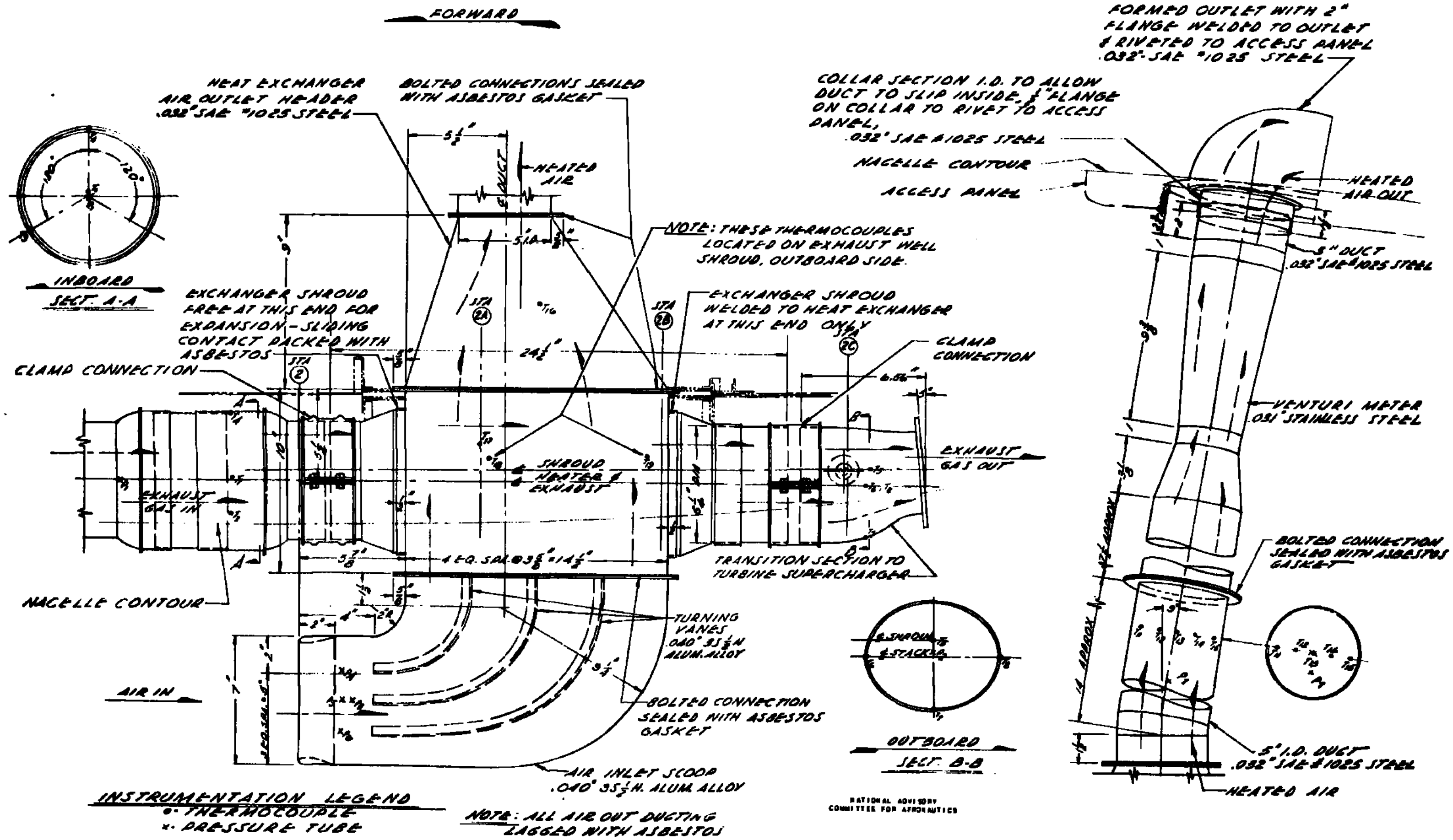

FIGURE 43.- HEAT EXCHANGER 5 INSTALLATION IN NACELLE 4, SIDE VIEW, B-17F AIRPLANE.

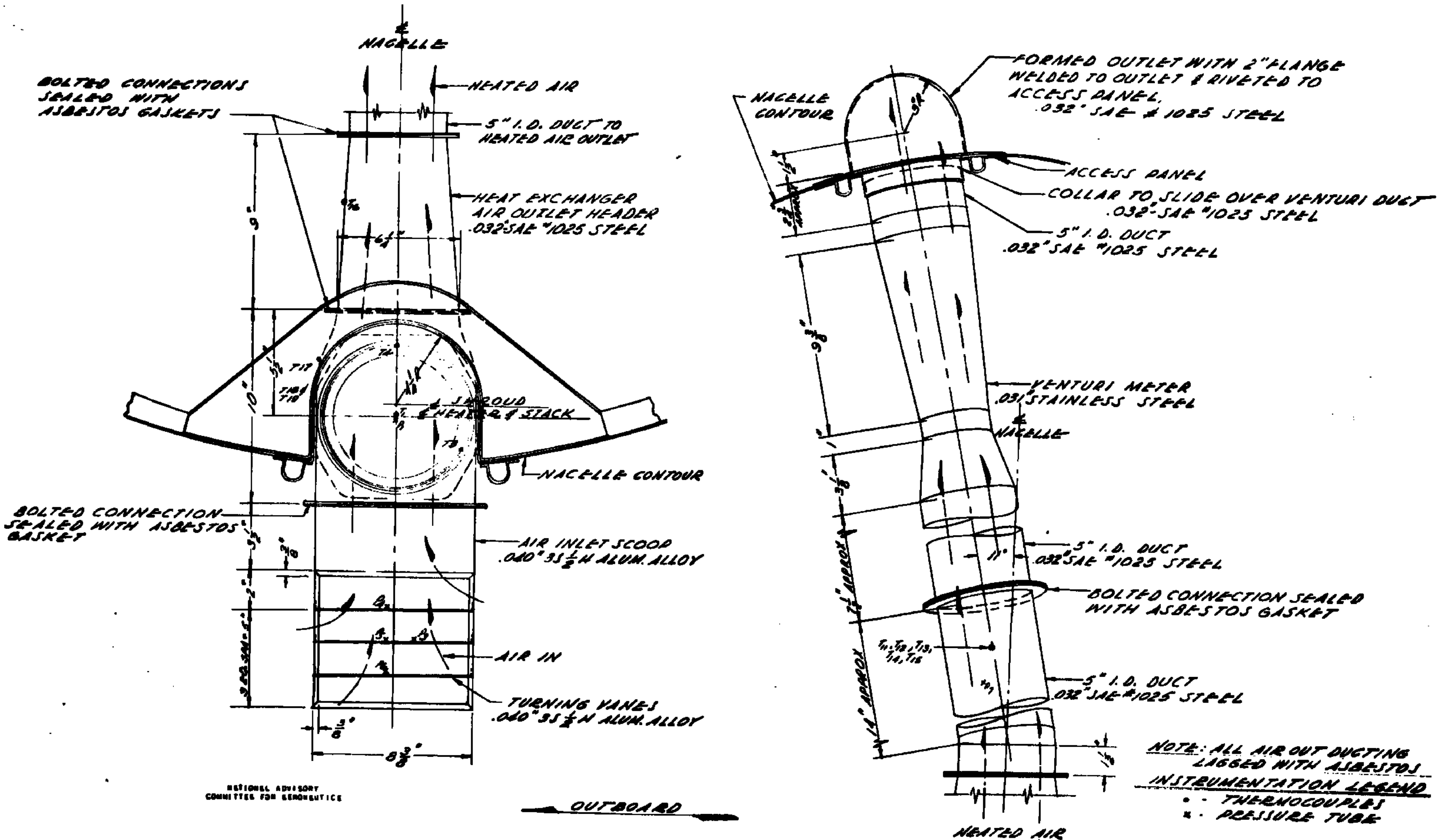

FIGURE 44.- HEAT EXCHANGER 5 INSTALLATION IN NACELLE 4, FRONT VIEW, B-17F AIRPLANE.

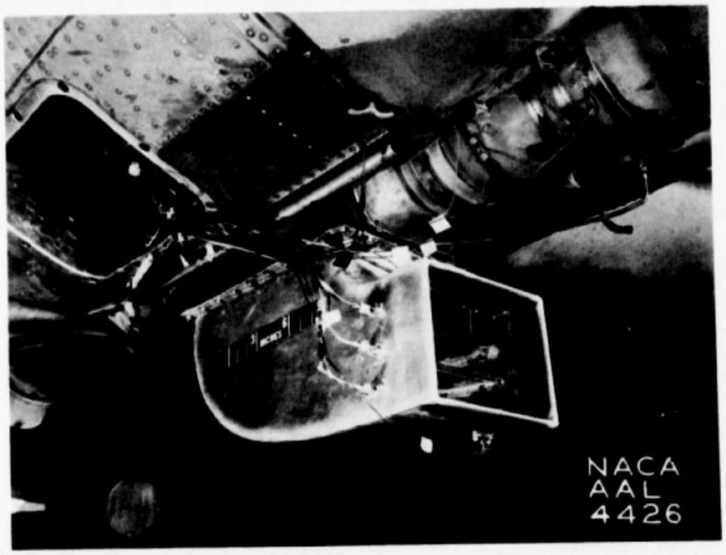

Figure 45.- Heat exchanger 5 installation in nacelle 4, ready for flight. B-17F airplane.

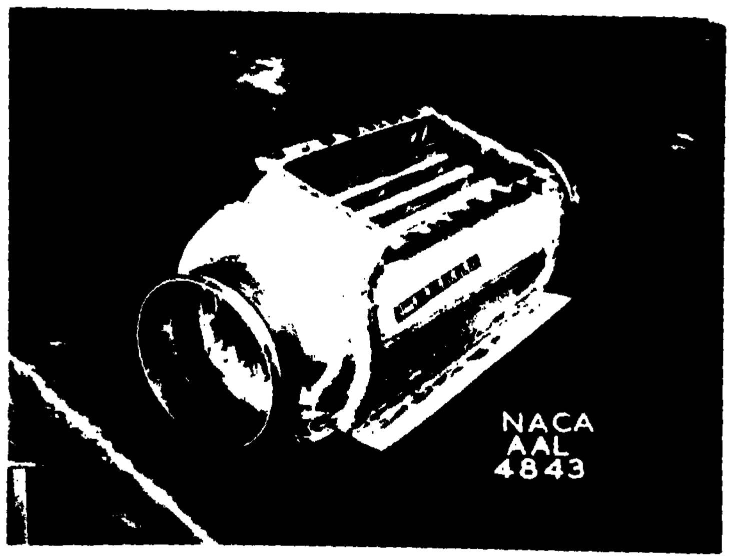

Figure 46.- Heat exchanger 5 shrouded for final installation in nacelle 1 of the B-17F airplane.

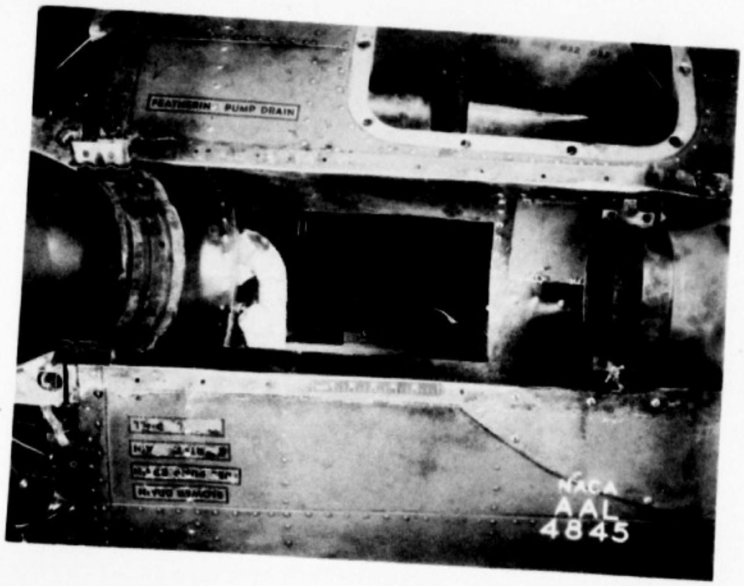

Figure 47.- Nacelle 1 exhaust shroud altered for final installation of heat exchanger 5. B-17F airplane.

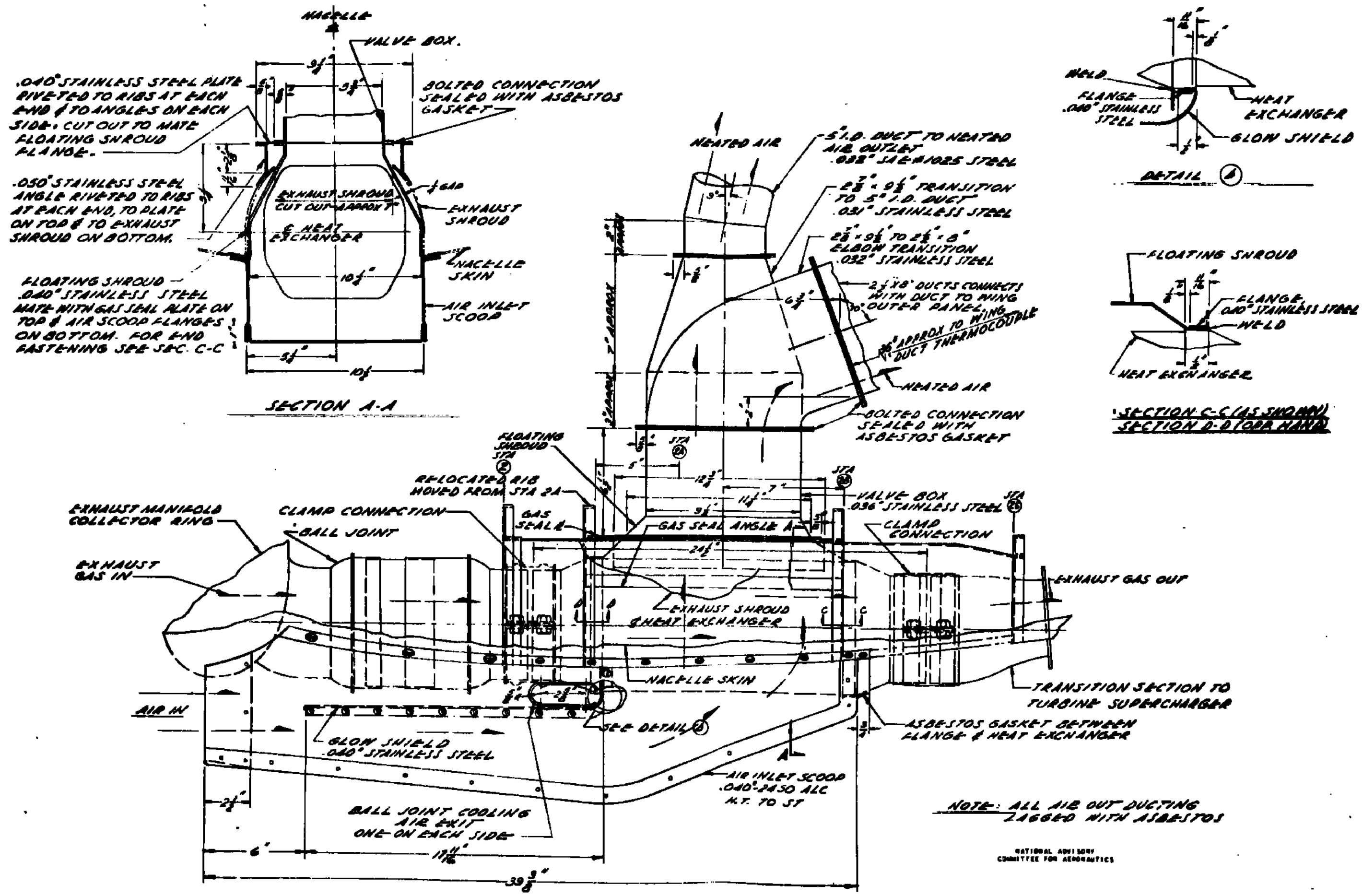

FIGURE 48.- FINAL INSTALLATION OF HEAT EXCHANGER 5 IN NACELLE 1, SIDE VIEW, B-17F AIRPLANE.

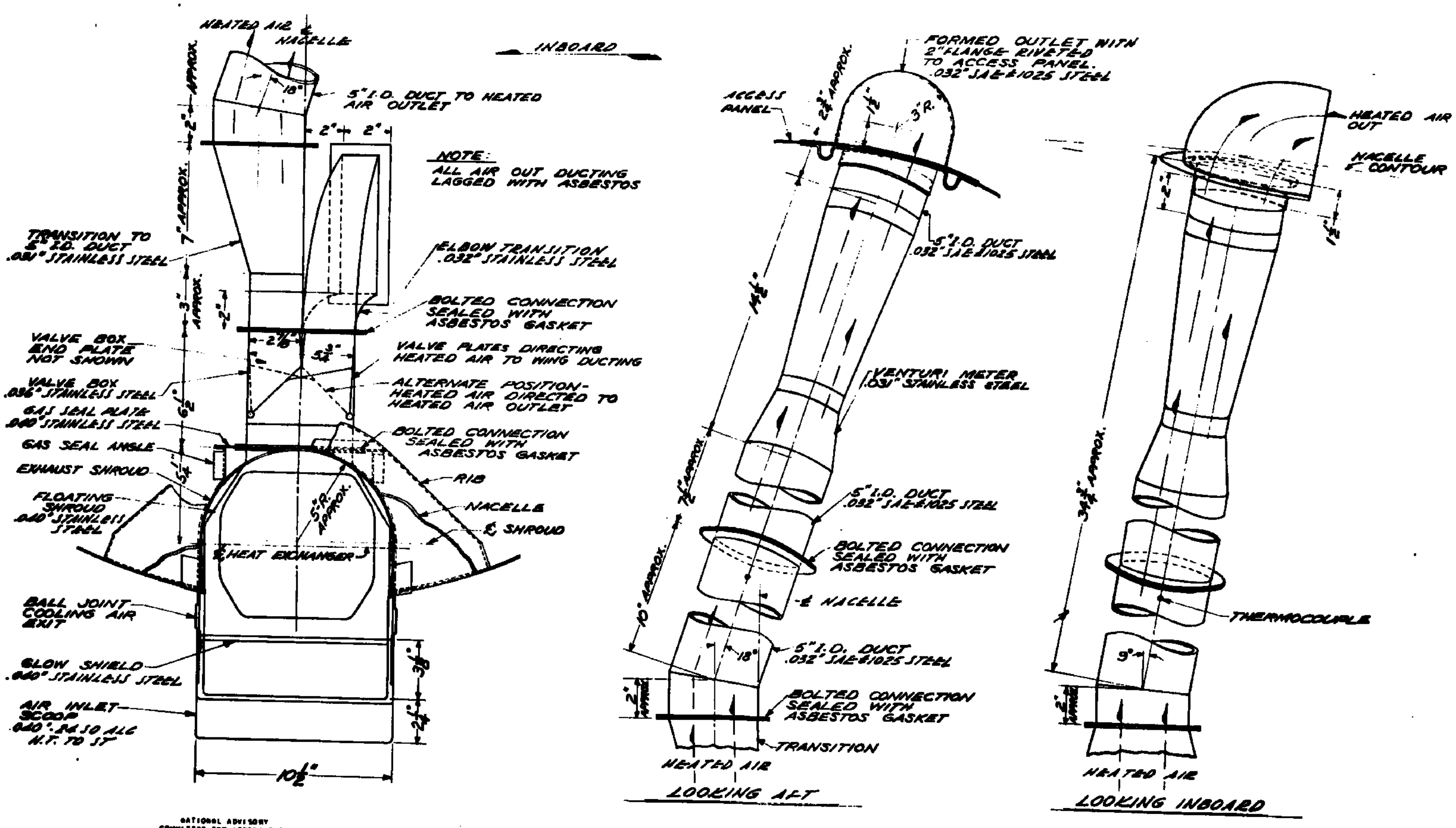

FIGURE 49.- FINAL INSTALLATION OF HEAT EXCHANGER 5 IN NACELLE 1, FRONT VIEW, AND DUCTING TO HEATED AIR OUTLET, B-17F AIRPLANE.

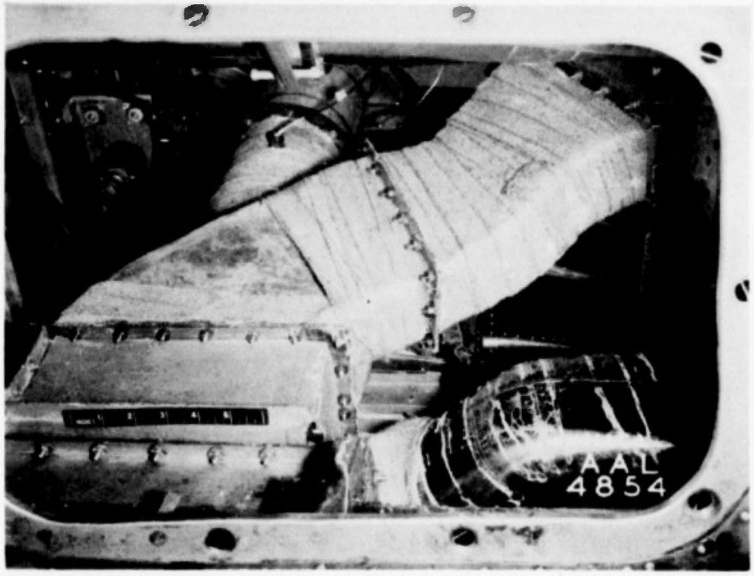

Figure 50.- Heated-air ducting for final installation of heat exchanger 5 in nacelle 1; to direct air to the left wing outer panel or overboard. B-17F airplane.

Figure 51.- Final installation of heat exchanger 5 in nacelle 1 of the B-17F airplane, ready for flight.

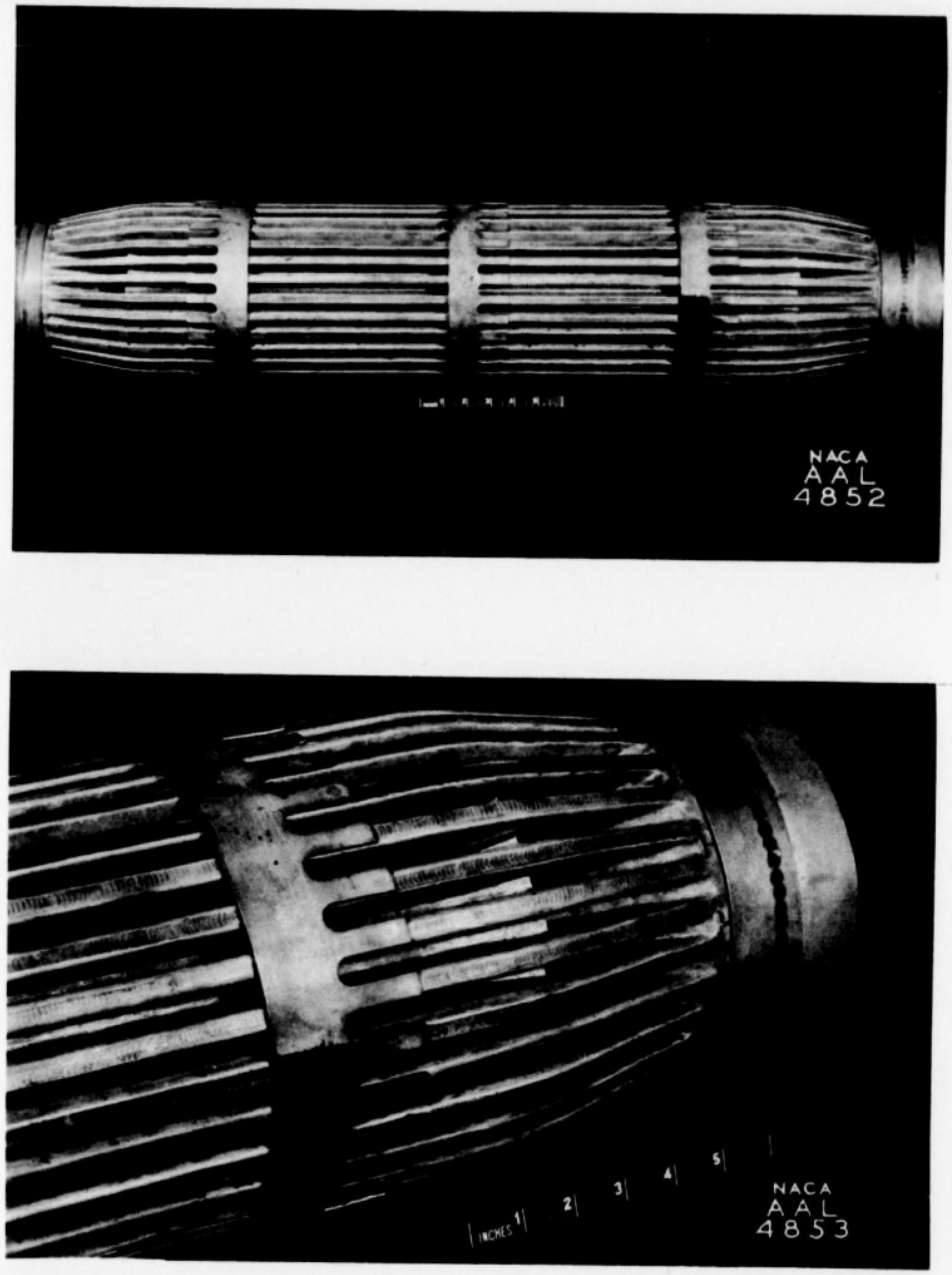

Figure 52.- Heat exchanger 7 used for final installation in nacelle 3 of the B-17F airplane.

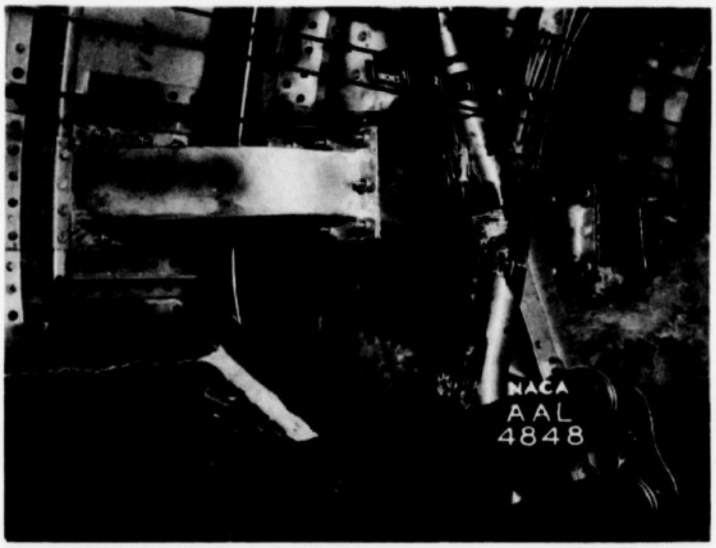

Figure 53.- Cold-air-tempering system for final installation of exchanger 7 in nacelle 3 showing ducting from inlet on side of nacelle to heated-air outlet from heat exchanger. B-17F airplane.

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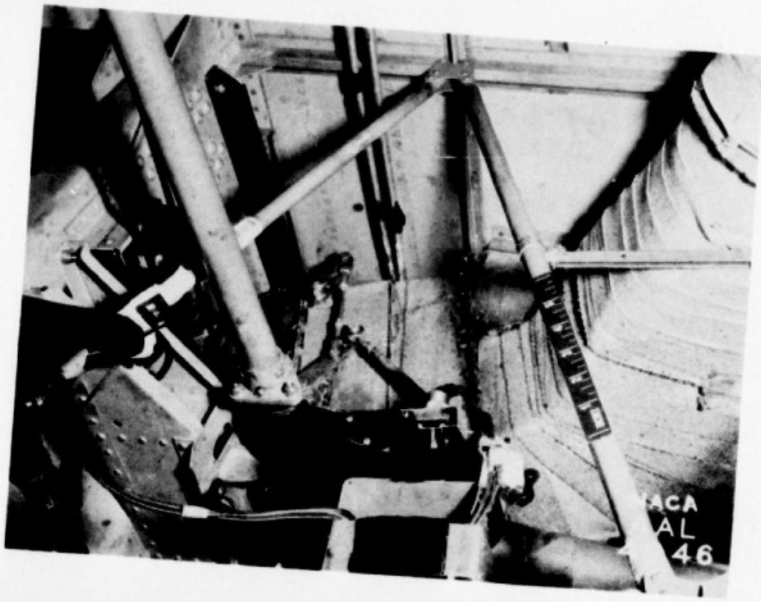

Figure 54.- Valve system in heated-air ducting from nacelle 3; to direct air to empennage or overboard. B-17F airplane.

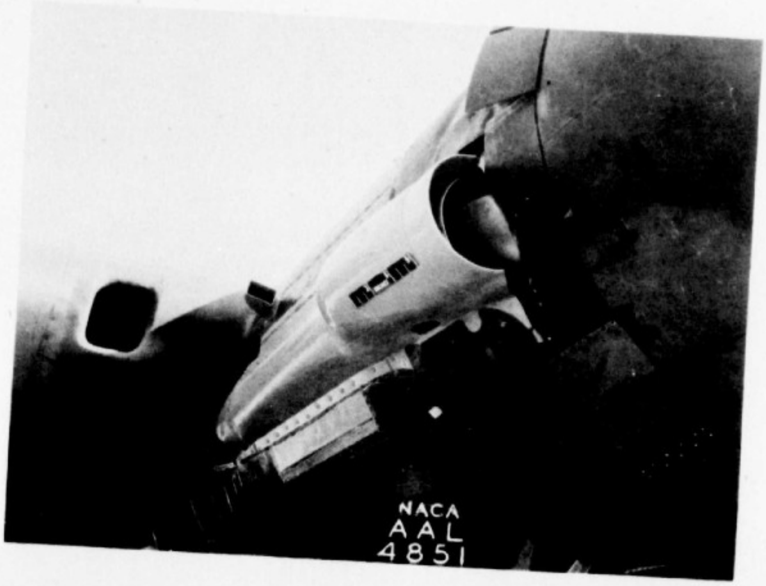

Figure 55.- Final installation of heat exchanger 7 in nacelle 3 of the B-17F airplane, ready for flight. Inlet for air-tempering system is on side of nacelle above and aft of exchanger air inlet.

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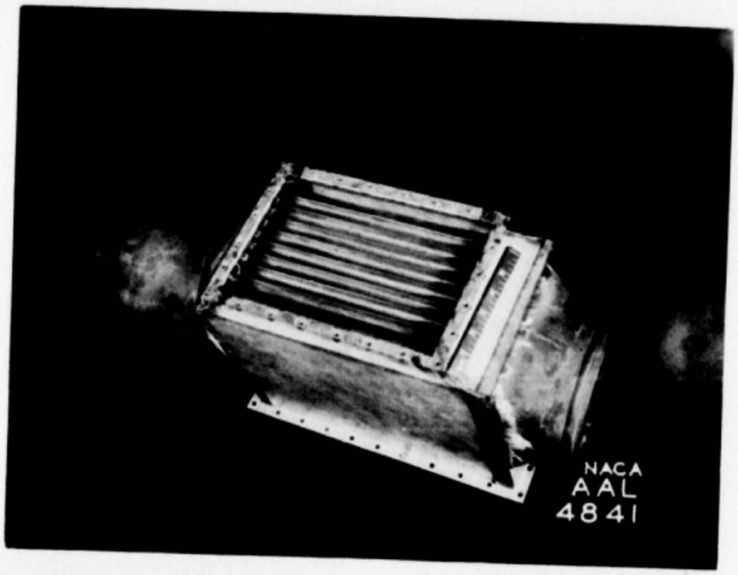

Figure 56.- Heat exchanger 3 shrouded for final installation in nacelle 4 of the B-17F airplane.

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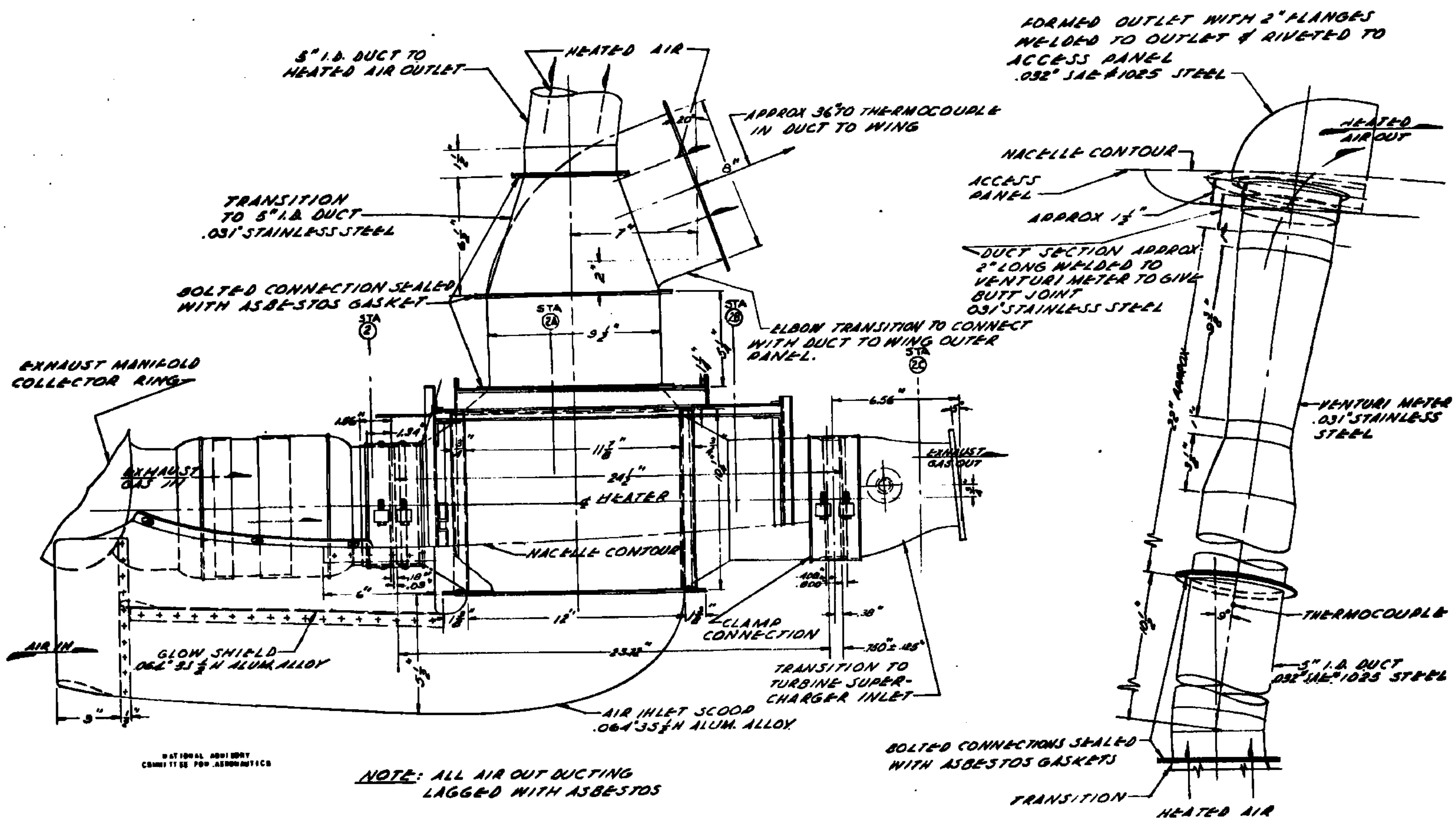

NOTE: ALL AIR OUT DUCTING LAGGED WITH ASBESTOS

FIGURE 57.- FINAL INSTALLATION OF HEAT EXCHANGER 3 IN NACELLE 4, SIDE VIEW B-17F AIRPLANE.

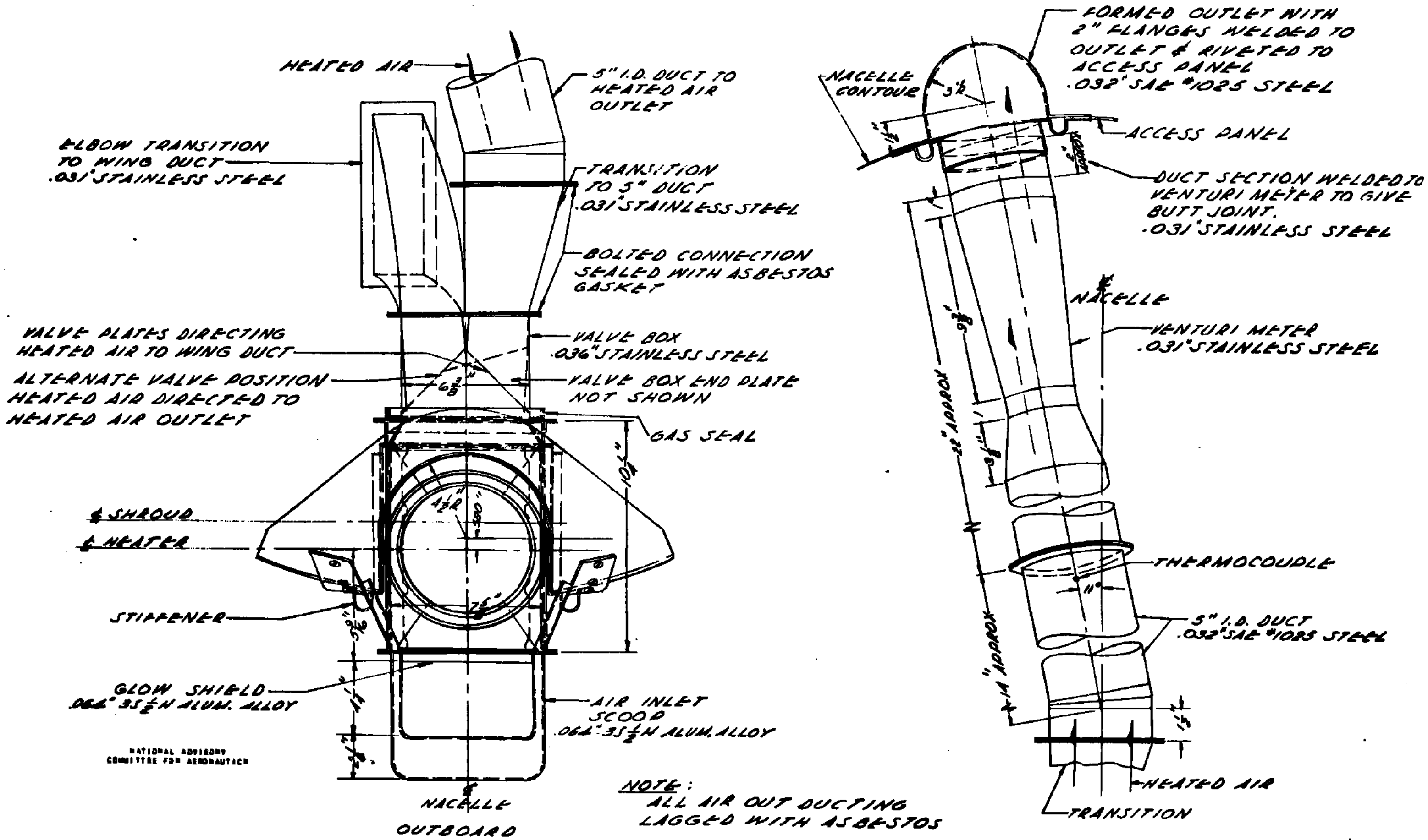

FIGURE 58.- FINAL INSTALLATION OF HEAT EXCHANGER 3 IN NACELLE 4, FRONT VIEW, B-17F AIRPLANE.

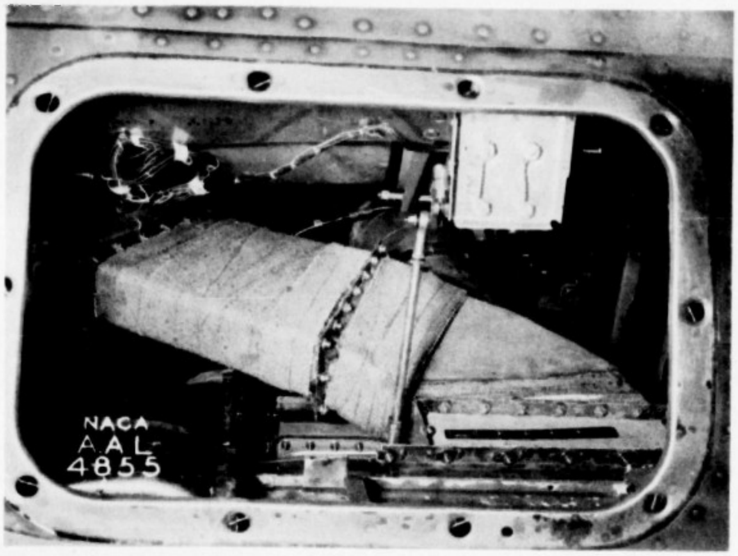

Figure 59.- Heated-air ducting for final installation of heat exchanger 3 in nacelle 4; to direct air to the right wing outer panel or overboard. B-17F airplane.

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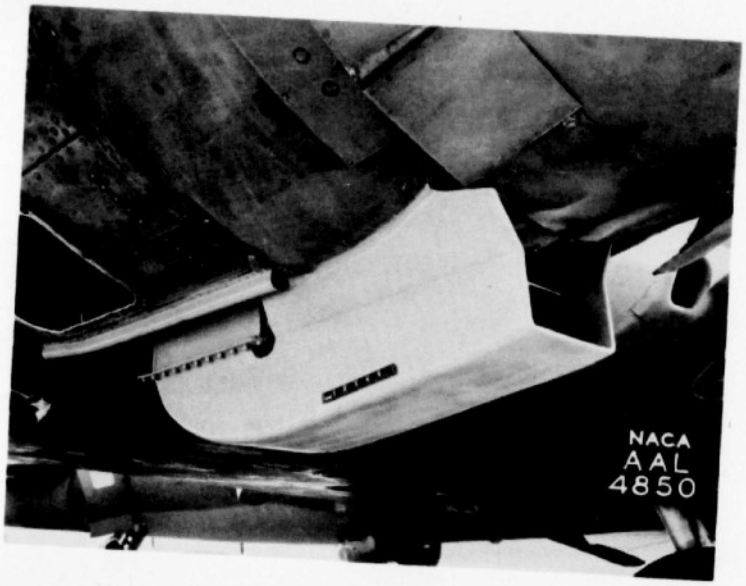

Figure 60.- Final installation of heat exchanger 3 in nacelle 4 of the B-17F airplane, ready for flight.

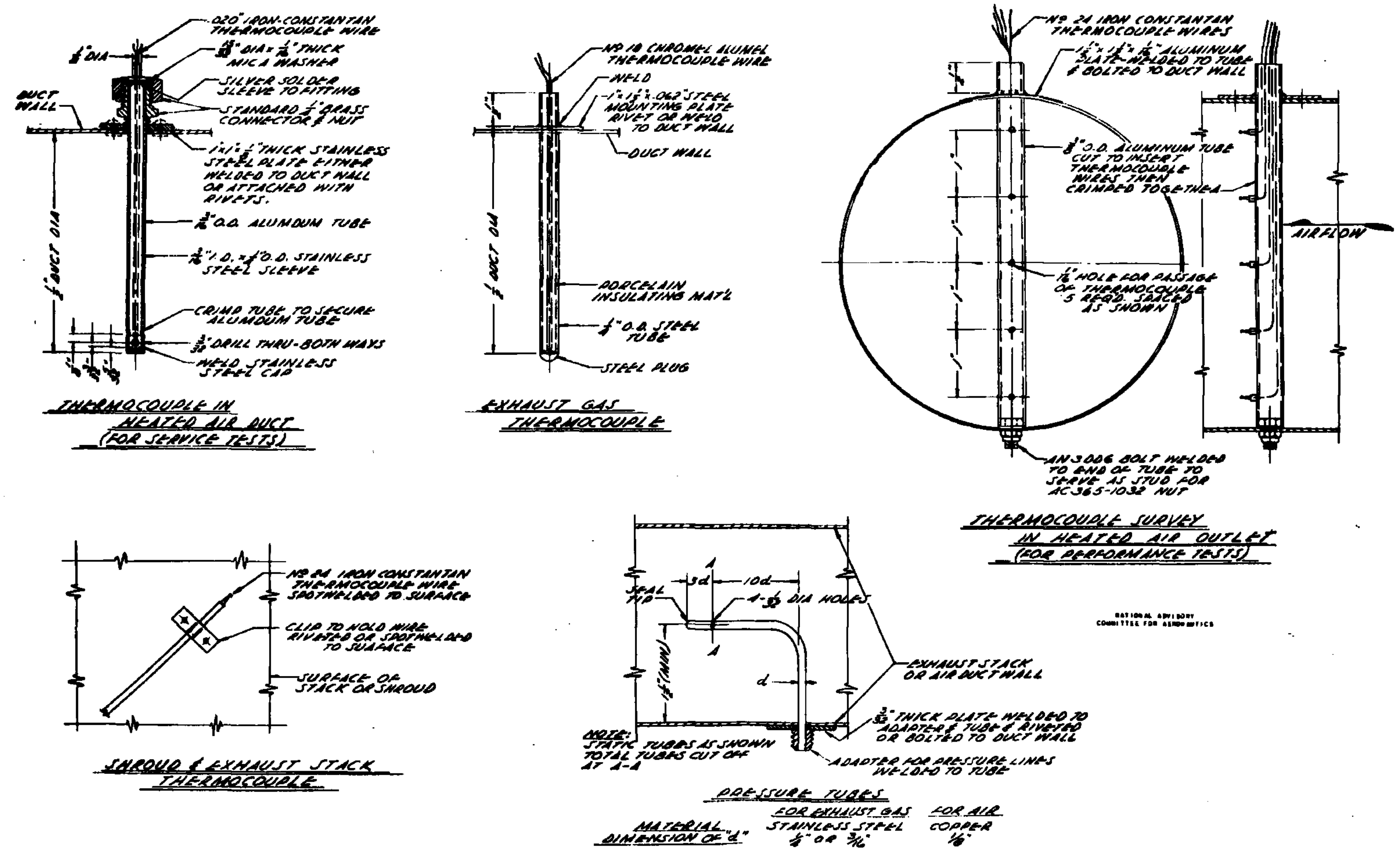

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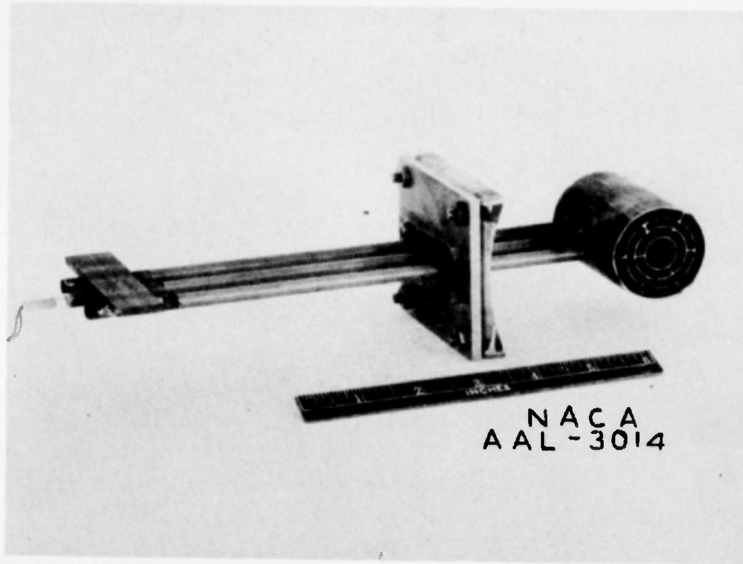
FIGURE 61.- DETAILS OF TYPICAL THERMOCOUPLE AND PRESSURE TUBE INSTALLATIONS USED FOR HEAT EXCHANGER TESTS ON THE B-17F AIRPLANE.



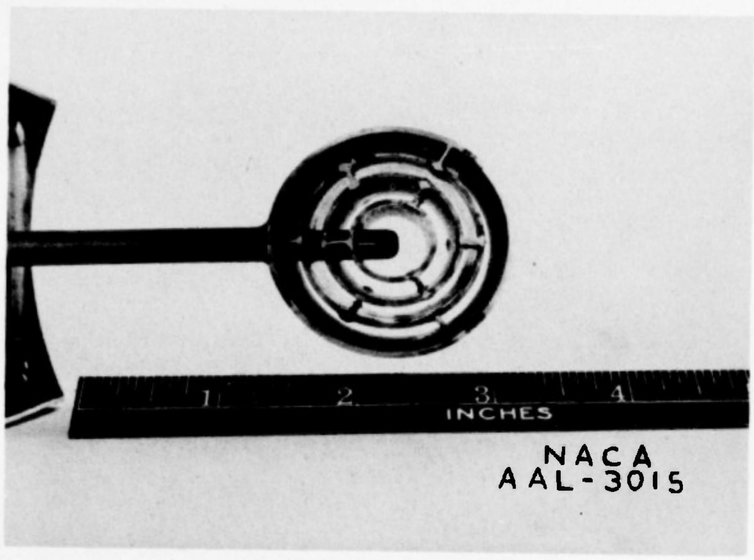


Figure 62.- Quadruple-shielded thermocouple used to measure exhaust-gas temperatures. B-17F airplane.

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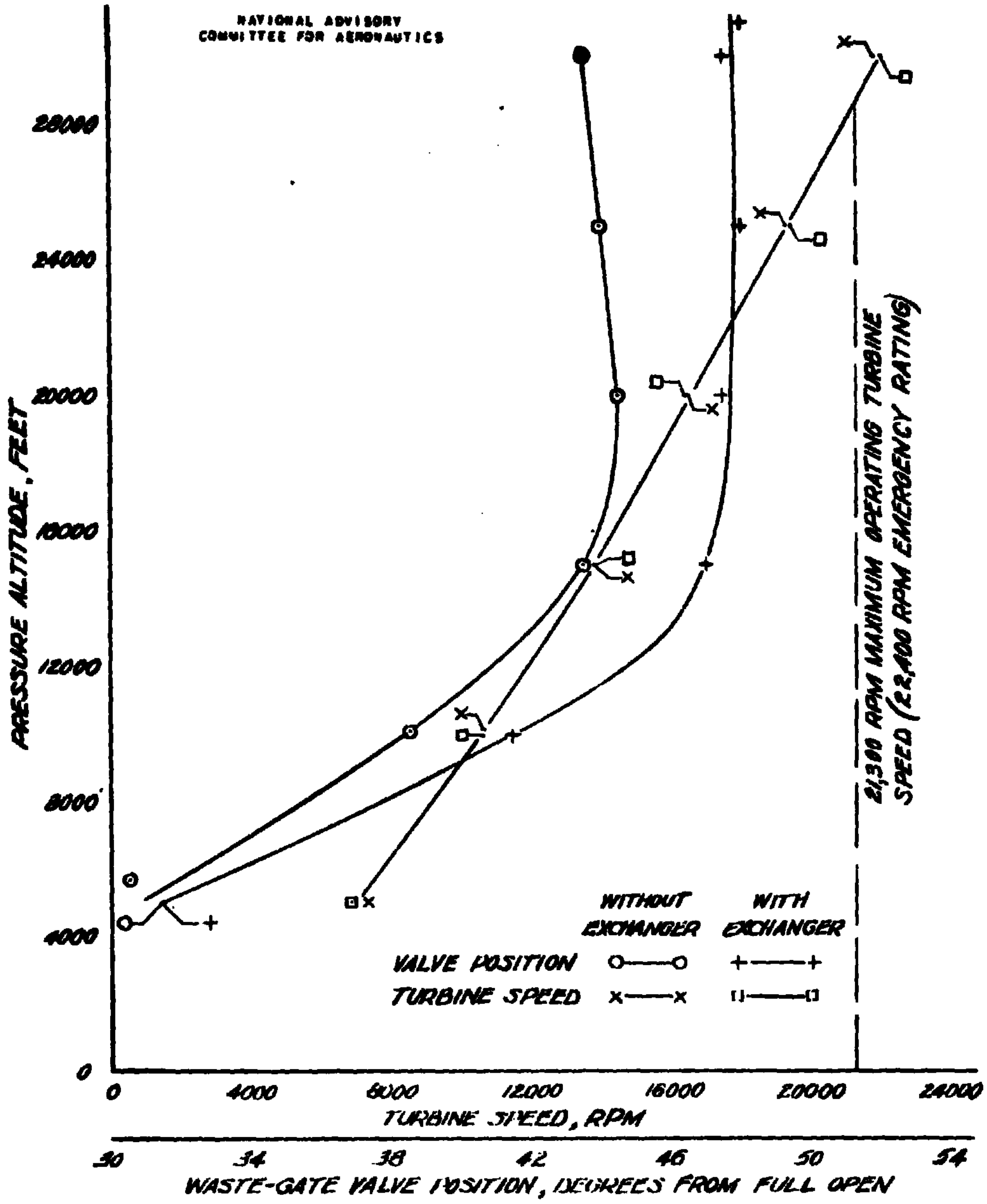

FIGURE 63.-VARIATION OF TURBINE SUPERCHARGER SPEED AND WASTE-GATE VALVE POSITION DURING CLIMB. B-17F AIRPLANE; ENGINE 3; WITH AND WITHOUT HEAT EXCHANGER 7 INSTALLED. CONDITIONS DURING CLIMB: M.P. 38±1 INCHES OF MERCURY; ENGINE SPEED, 2300 RPM; INDICATED AIR SPEED 150±5 MPH; FULL THROTTLE; MANIFOLD PRESSURE MAINTAINED CONSTANT WITH BOOST CONTROL.

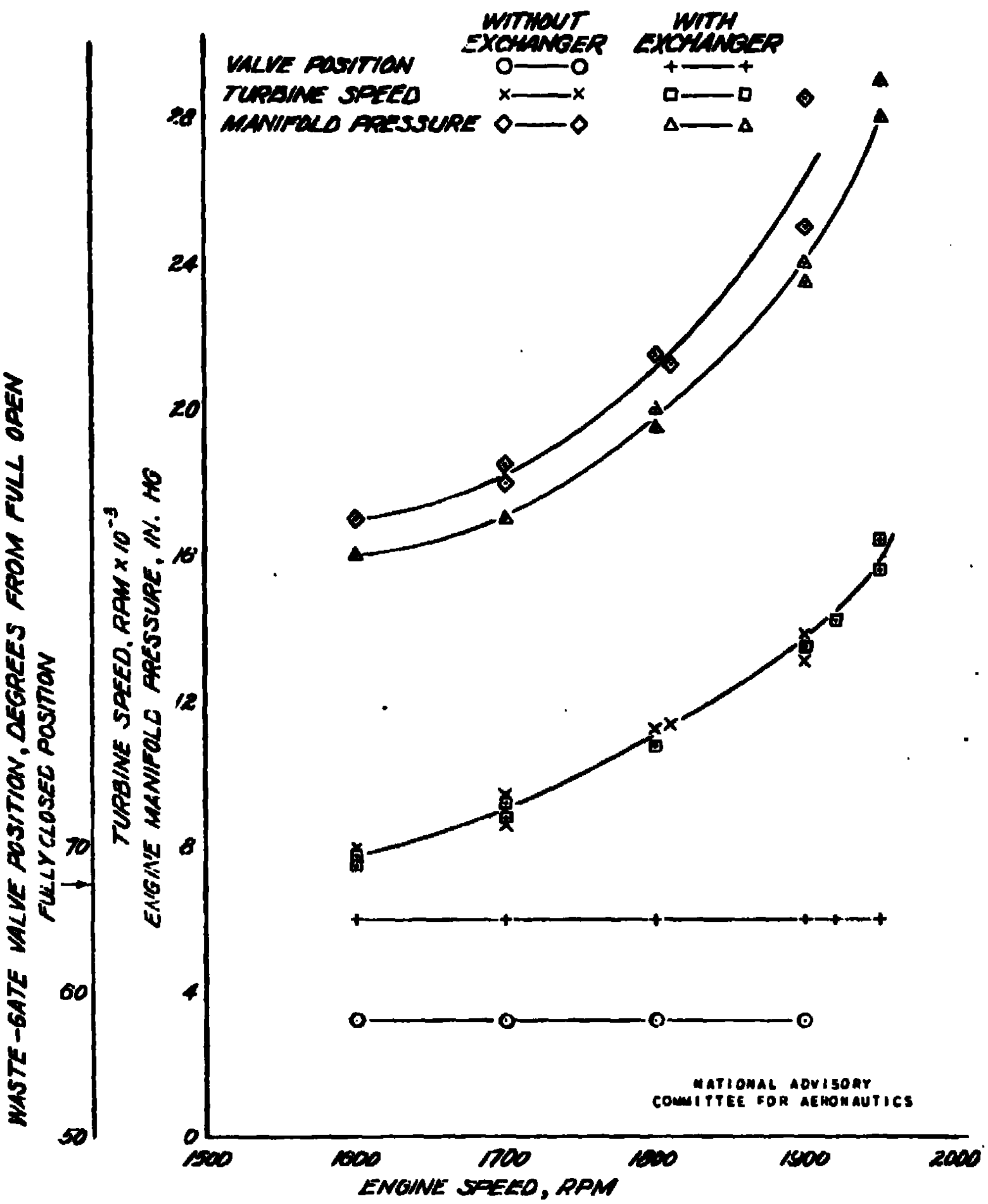

FIGURE 64.- VARIATION OF TURBINE SUPERCHARGER SPEED, WASTE-GATE VALVE POSITION, AND ENGINE MANIFOLD PRESSURE WITH ENGINE SPEED IN LEVEL FLIGHT. B-17F AIRPLANE; ENGINE 3; WITH AND WITHOUT HEAT EXCHANGER 7 INSTALLED. TEST CONDITIONS: PRESSURE ALTITUDE 25,000 FEET; FULL THROTTLE; FULL BOOST: ENGINE SPEED VARIED BY PROPELLER PITCH CONTROL.

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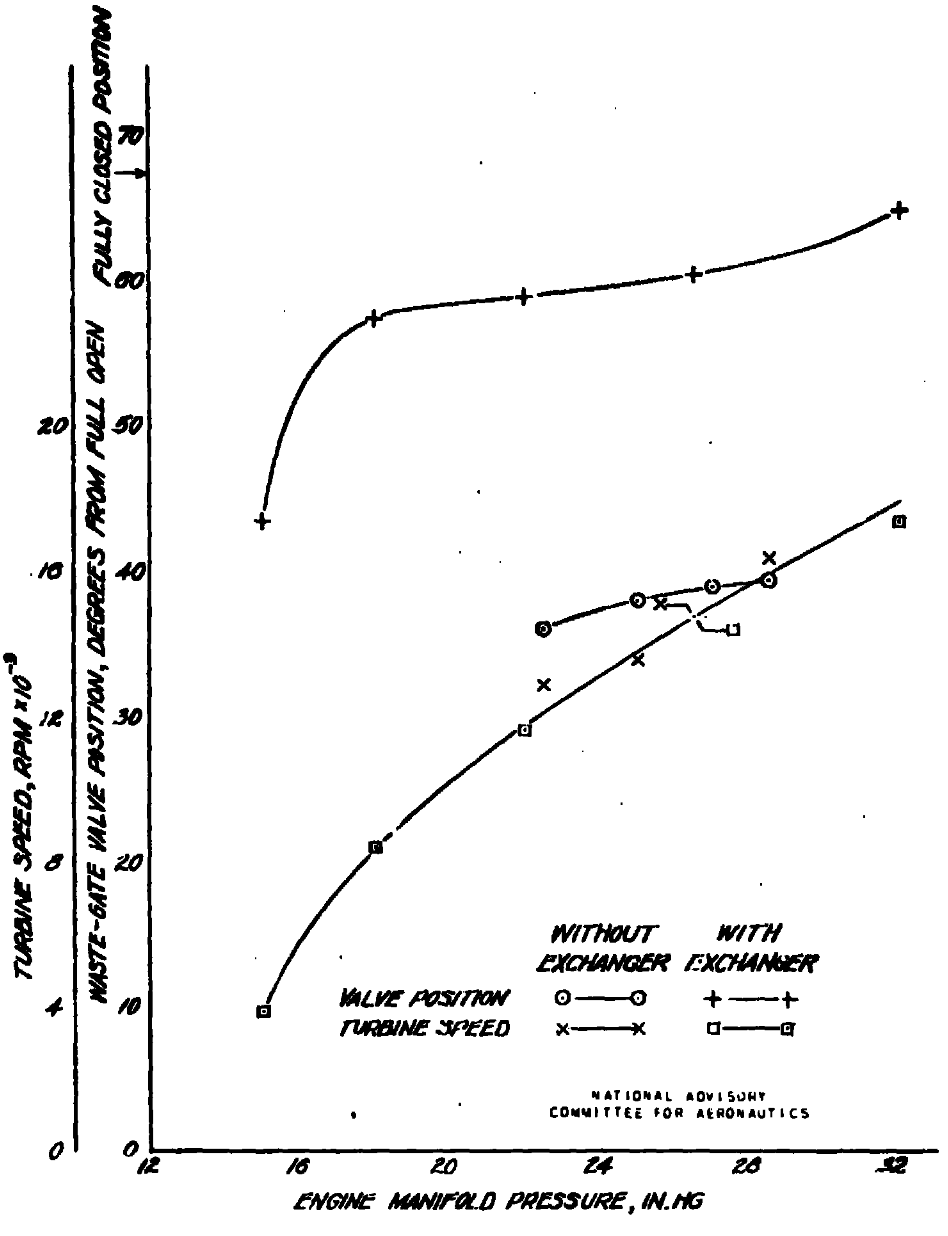

FIGURE 65.—VARIATION OF TURBINE SUPERCHARGER SPEED AND WASTE-GATE VALVE POSITION WITH ENGINE MANIFOLD PRESSURE IN LEVEL FLIGHT B-17F AIRPLANE; ENGINE 3; WITH AND WITHOUT HEAT EXCHANGER 7 INSTALLED. TEST CONDITIONS: PRESSURE ALTITUDE, 25,000 FEET; ENGINE SPEED, 2000 RPM; FULL THROTTLE; MANIFOLD PRESSURE VARIED BY BOOST CONTROL.

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DIVISION no. 2

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AUTHOR(S): Look, Bonne C.; Seina, James
ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D. C.

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Aircraft Engines, Heat Exchangers

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