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HEAT-TRANSFER TESTS OF A STEEL CYLINDER BARREL WITH ALUMINUM FINS WITH IMPROVED BONDING BETWEEN STEEL BARREL AND ALUMINUM BASE

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MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

HEAT-TRANSFER TESTS OF A STEEL CYLINDER BARREL WITH ALUMINUM FINS WITH IMPROVED BONDING BETWEEN STEEL BARREL AND ALUMINUM BASE

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INTRODUCTION

The finning of conventional cylinder barrels cannot be improved to any great extent except by adding fin weight which means, in general, fin width (references 1 and 2). By a conventional cylinder barrel is meant a steel barrel with steel fins. For in-line engine and in some cases radial engine installations the width of the barrel fins is limited and a possible solution of the barrel-cooling problem is to use preformed aluminum fins on a steel barrel. If a reasonably satisfactory bond between the aluminum and steel is obtained, the heat transfer of the barrel should be greatly improved.

At the request of the Bureau of Aeronautics, Navy Department, a steel cylinder barrel with aluminum fins was tested by this laboratory (reference 3). The preformed fins of that cylinder were imbedded in an aluminum base, which in turn was bonded to the steel barrel. The tests showed that the bond between the fins and the aluminum base was very good but that the heat-transfer coefficients based on the steel temperatures were about 18 percent below the coefficients calculated from the aluminum base temperatures indicating that the bond between the aluminum base and the steel was not very good.

The present report presents the results of tests made on another steel cylinder barrel with aluminum fins. The method of attaching the fins to the steel for this cylinder is similar to that of the first cylinder tested, but the method of attaching the aluminum base to the steel barrel was thought to be an improvement over that used for the first cylinder. The object of the tests was to determine the heat-transfer coefficients of the cylinder and the excellence of the bond between the aluminum fins and the aluminum base and between the aluminum base and the steel. The tests were made at the request of the Bureau of Aeronautics, Navy Department.

APPARATUS

Test Cylinder

The test cylinder was a complete barrel for an engine cylinder and was made of steel with aluminum fins. The space between the fins was 0.052 inch, the thickness of the fins 0.025 inch, and the width 0.375 inch. The bottom and top of the barrel were cut off to leave only the finned section for the test specimen (fig. 1). The cylinder was electrically heated with a wire coil wound on a soapstone core, which was inserted in the cylinder. Loss of heat from the ends of the cylinder was eliminated by using cylindrical guard rings made of sheet metal and filled with rock wool. The method of heat insulation is fully illustrated in reference 3.

Surface temperatures and base temperatures were obtained at 29 points on the cylinder by means of iron-constantan thermocouples made from No. 40 gage wire. The locations for the thermocouples were the same as for the cylinder reported in reference 3. The thermocouple wires were shellacked to the fins and brought out through a tube to a cold junction board, as shown in figure 1. The method of attaching the junctions of the thermocouples to the steel base of the first cylinder tested (reference 3) was to scrape away some of the aluminum base and insert the thermocouples in the space provided (fig. 2(a)). In the present tests two methods were used. In the first method a hole was drilled in the aluminum base of the cylinder down to the steel (fig. 2(b)). A plug of duralumin with a hole in it, through which the wires of a thermocouple were inserted, was placed in the hole. The wires were soldered together before the plug was placed in the hole and solder was placed in the bottom of the hole. The cylinder was heated on the inside, the solder melted, and the plug was pushed down in the hole. The heat was removed and the plug peened around the edge A, figure 2(b), to hold it in place. The top of the plug was then covered with bakelite varnish to make a seal and a smooth surface. The second method used in the present tests was similar to the first with the exception that two plugs were used side by side with one wire of a thermocouple in each plug (fig. 2(c)). No solder was used in the second method, the plug being pushed down and held in place by peening the edge A. This second method of attaching the thermocouple wires was used to insure insulation of one wire of a thermocouple from the other wire. The wires of the thermocouples in the first method were shellacked. The second method was used as a check on the first method.

An ammeter and voltmeter were used to measure the electrical input to the cylinder and a potentiometer measured the cylinder temperatures.

Jacket

The cylinder was enclosed in a wood jacket and air drawn over the setup with a blower as illustrated in reference 3. The jacket shape and apparatus used for such a test are fully described in references 4 and 5. The jacket fitted tight against the fin tips and guard rings. The weight of air passing through the jacket was measured with thin-plate orifices placed in the ends of a large tank. Temperatures of the air at the orifices and of the cold junction were obtained with alcohol thermometers.

METHODS

Tests

The weight velocity of the cooling air over the fins was varied from approximately 2 to 13 pounds per square foot of free area between the fins by varying the speed of the blower. All tests were conducted with an approximately constant heat input to the cylinder of 77 Btu per square inch of wall area per hour. The recorded data were the electrical power input to the test cylinder, the temperature of the air entering the orifice tank, the pressure drop across the orifice tank, the cold junction temperature, and the temperatures at the various points on the cylinder.

Computations

The weight velocity of the cooling air $V\rho_1 g$ over the fins was calculated by dividing the weight of the air passing through the jacket by the free-flow area between the fins.

The method of calculating the weight of air passing through the jacket is given in reference 6.

The experimental average over-all heat-transfer coefficient U was obtained by dividing the heat input per hour by the product of the area of the wall surface of the cylinder and the difference between the average temperature of the wall surface the entering-air temperature.

Calculated average over-all heat-transfer coefficient U was obtained from the equation

$$U = \frac{q}{s+t}\left[\frac{2}{a}\left(1+\frac{w}{2R_b}\right)\tanh aw' + s\right] \qquad (1)$$

as derived in reference 7, where

$a = \sqrt{\frac{2q}{k_m t}}$

q surface heat-transfer coefficient, Btu per square inch per °F per hour.

s average space between fins, inches

t average fin thickness, inches

w fin width, inches

w' $w + {}^{t}/2$, effective fin width, inches

R_b radius from center of cylinder to fin root, inches

k_m thermal conductivity of metal, Btu per square inch per °F through 1 inch per hour (2.17 for steel; 9.92 for pure aluminum)

This equation has been experimentally verified for fins of steel, copper, and aluminum alloy. (See references 1, 2, 4, 7, and 8.)

RESULTS AND DISCUSSION

Heat-Transfer Tests

The surface heat-transfer coefficients q of finned cylinders have been correlated for an air-flow arrangement as used in the present tests (reference 8). Thus it has been found for cylinders enclosed in a jacket and cooled by a blower,

$$\frac{qs}{k_a} = f\left(\frac{V\rho_1 \, gs^2}{12\mu D \; 0.25}\right) \qquad (2)$$

where

k_a thermal conductivity of the cooling air

μ absolute viscosity of the cooling air

D diameter of cylinder at fin root ($2R_b$)

Figure 9(d) of reference 8 shows a curve, established from tests on a large number of cylinders with an air-flow arrangement as in the present tests, plotted in terms of functions of the foregoing equation. Surface heat-transfer coefficients for a cylinder with fin and cylinder dimensions the same as for the test cylinder were calculated from this curve for several weight velocities between the fins. From these calculated surface heat-transfer coefficients, over-all heat-transfer coefficients were calculated according to equation (1) for a steel cylinder with steel fins and for an aluminum cylinder with aluminum fins cast integrally. The dimensions of the fins in these calculations were the same as for the test cylinder, and the aluminum fins were assumed to have a conductivity of 9.92 Btu per square inch per °F per hour through 1 inch. The results are plotted in figure 3. The experimental coefficients are also plotted on figure 3 based on both the temperature difference between the aluminum base and the cooling air and the temperature difference between the steel base and the cooling air for methods B and C of attaching the thermocouples.

The experimental coefficients calculated on the two temperature bases for both methods B and C of attaching the thermocouples fall around the same curve in figure 3. This curve is about 12 percent higher than the calculated curve for aluminum fins cast integrally. The difference may be due to the conductivity of the aluminum in the test cylinder being different from that assumed in the calculations (9.92 Btu per square inch per °F per hour through 1 in.) or to the fact that the calculations made using the correlation curve cannot be expected to check any one cylinder test with a closer accuracy. Test points around the correlation curve of reference 8 are as much as 15 percent from the curve. The comparison of the experimental coefficients based on the difference between the temperatures of the aluminum base and the cooling air and the calculated coefficients for the aluminum fins cast integrally indicates that the bond between the fins and the aluminum base is very good. The comparison of the experimental coefficients based on the temperature of the steel and the experimental coefficients based on the temperatures of the aluminum base for method C of attaching the thermocouples shows that the bond between the steel and aluminum bases is good. In general, for method C, the experimental coefficients based on the aluminum temperatures was a little greater, about 4 percent at the most, than the coefficients based on the steel temperatures. This difference, however, is within the experimental error of the tests, and it can be concluded again that the bond between the aluminum base and the steel is good.

Comparison of the experimental coefficients for the test cylinder with the calculated coefficients for the steel cylinder with steel fins in figure 3 shows an improvement in heat transfer of approximately 20 percent by using aluminum fins. Comparison of the calculated coefficients for steel and aluminum fins in figure 3, shows that by using aluminum instead of steel the heat transfer can be improved approximately 17 percent. Reference 2 shows further that for fins 3/8 inch wide, the width of those on the test cylinder, the maximum heat transfer is obtained with a fin space of 0.09 inch with a pressure difference across the cylinder of 4 inches of water, which is generally the pressure difference available in conventional airplanes. Figure 4 shows calculated coefficients for two cylinders with aluminum fins cast integrally for various pressure differences across the cylinders. One cylinder has fins of the same dimensions as the test cylinder and the other cylinder has the same fin width and thickness as the test cylinder but the fin space is 0.09 inch. At a pressure difference of 4 inches of water the heat transfer is increased 18 percent by using a fin space of 0.09 inch instead of 0.052 inch. It should thus be possible to make a cylinder similar to the one tested with fins of 0.09 inch space and increase the heat transfer of a cylinder with steel fins about 35 percent. As the pressure difference available for cooling increases, the difference in heat transfer between the two fin designs decreases, figure 4, until a point is reached where the closer fin spacing gives the highest heat transfer.

Physical Tests

The cylinder was cut in half and one half was cut in quarters in order to determine how good the bonds between the steel and the aluminum base and between the fins and the aluminum base were mechanically. One edge of one of the quarters was polished and etched, and the result shown in figure 5(b). The edge of the first cylinder manufactured by this method and tested, reference 3, is shown in figure 5(a). The outline of the fins in the aluminum base is much fainter in figure 5(b) than in figure 5(a) although the time of etching in 5(b) was much longer. The mechanical bond between the fin and aluminum base should, therefore, be much better for the second cylinder tested than for the first.

The half of the test cylinder was heated ten times to 450° F and quenched in water at room temperature after each heating. No change in the mechanical bond could be noted visually. The steel was then pried loose from the aluminum and much less force was required than was necessary in a similar test of the first cylinder tested (reference 3). The test is considered rather severe, however, and the bond between the steel and aluminum will probably be satisfactory mechanically.

CONCLUSIONS

1. Heat-transfer tests indicate that the thermal bond between these aluminum fins and the aluminum base is very good and that the bond between the aluminum base and the steel barrel is satisfactory. The thermal bond between the aluminum base and the steel cylinder is considerably better than that of the first cylinder tested. The etching tests indicate that the mechanical bond between the aluminum fins and the aluminum base is better than in the previous tests but this improvement is not important because the thermal bond was considered satisfactory on the previous cylinder. It is very encouraging, however, that all-around improvements have been made.

2. The heat transfer of the test cylinder with aluminum fins was approximately 20 percent greater than the calculated values for a steel cylinder with steel fins of the same dimensions.

3. Calculations showed that increasing the fin spacing of the test cylinder from 0.052 to 0.09 inch will give an additional 18 percent increase in heat rejection for the same barrel temperature at a pressure difference across the cylinder of 4 inches of water.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 17, 1940.

REFERENCES

1. Biermann, Arnold E.: The Design of Metal Fins for Air-Cooled Engines. S.A.E. Jour., vol. 41, no. 3, Sept. 1937, pp. 388-392.

2. Biermann, Arnold E., and Ellerbrock, Herman H., Jr.: The Design of Fins for Air-Cooled Cylinders. NACA Rep. No. 726, 1941.

3. Ellerbrock, Herman H., Jr.: Heat-Transfer Tests of a Steel Cylinder Barrel with Aluminum Fins. NACA Memo. rep., Aug. 7, 1939.

4. Schey, Oscar W., and Ellerbrock, Herman H., Jr.: Blower Cooling of Finned Cylinders. NACA Rep. No. 587, 1937.

5. Rollin, Vern G., and Ellerbrock, Herman H., Jr.: Pressure Drop Across Finned Cylinders Enclosed in a Jacket. NACA TN No. 621, 1937.

6. Ware, Marsden: Description and Laboratory Tests of a Roots Type Aircraft Engine Supercharger. NACA Rep. No. 230, 1926.

7. Biermann, Arnold E., and Pinkel, Benjamin: Heat Transfer from Finned Metal Cylinders in an Air Stream. NACA Rep. No. 488, 1934.

8. Ellerbrock, Herman H., Jr., and Biermann, Arnold E.: Surface Heat-Transfer Coefficients of Finned Cylinders. NACA Rep. No. 676, 1939.

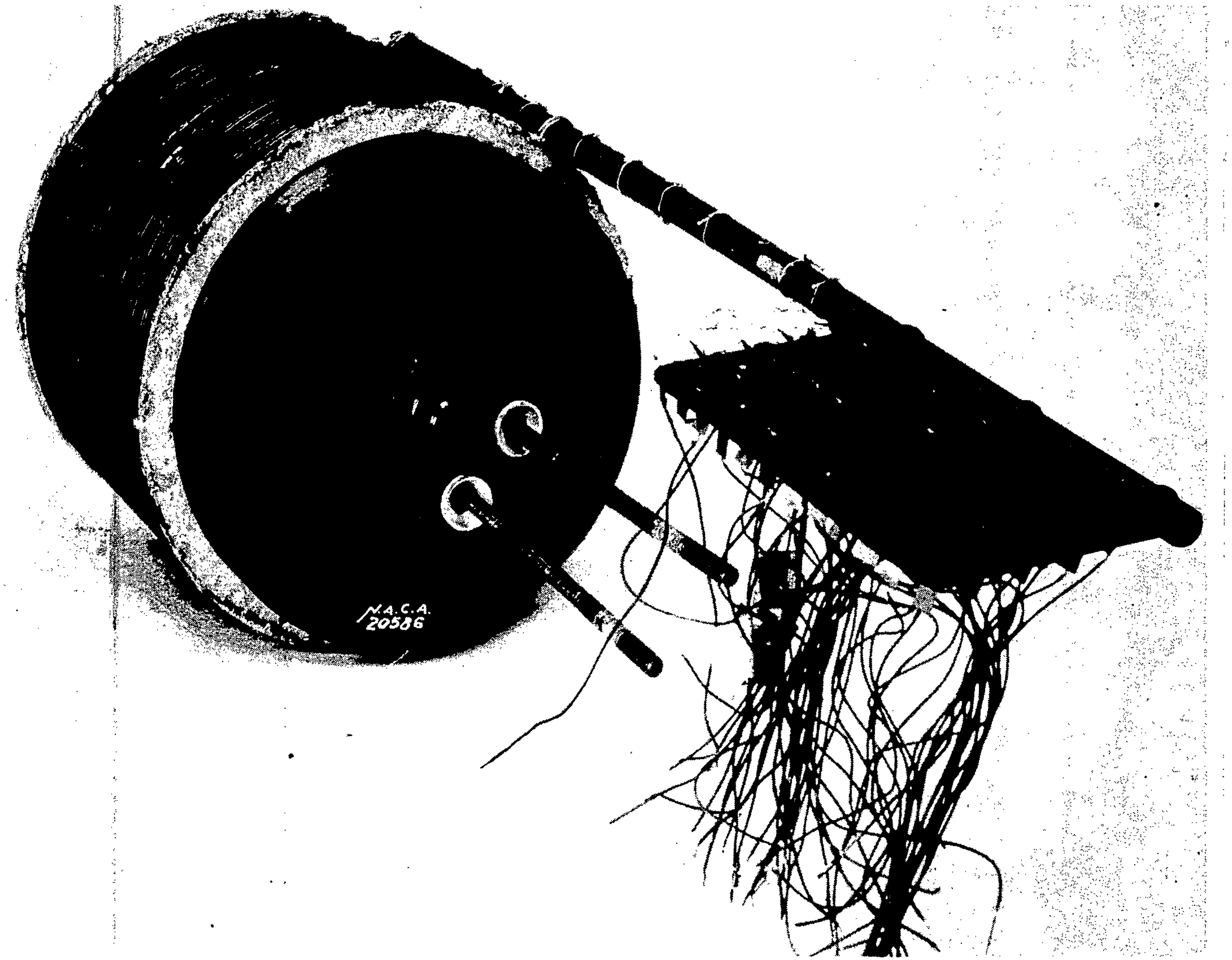

Figure 1. - Test cylinder with cold junction board attached and heating core inserted.

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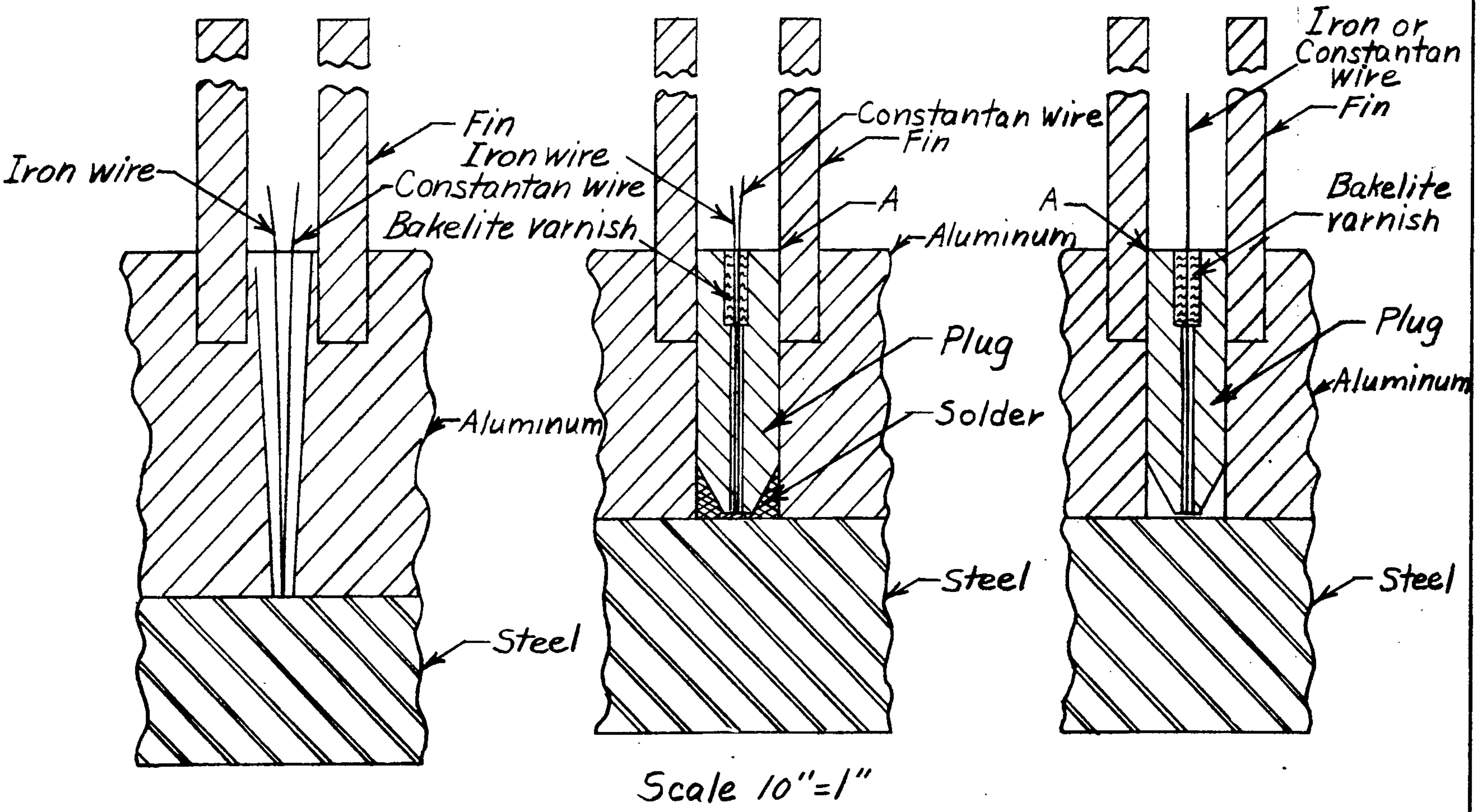

(a) Method A (b) Method B (c) Method C

Figure 2.-Methods of attaching thermocouples to steel base.

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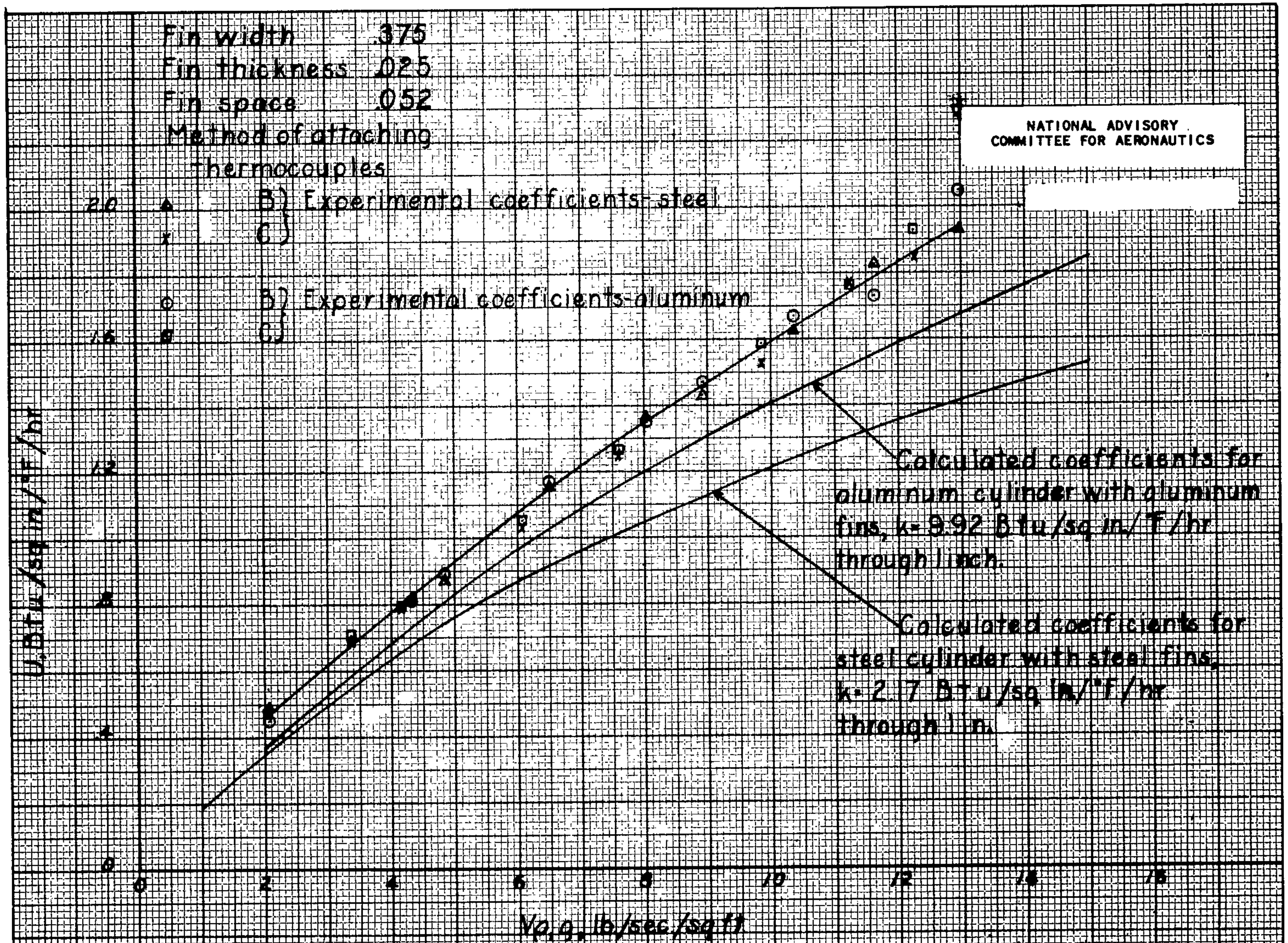
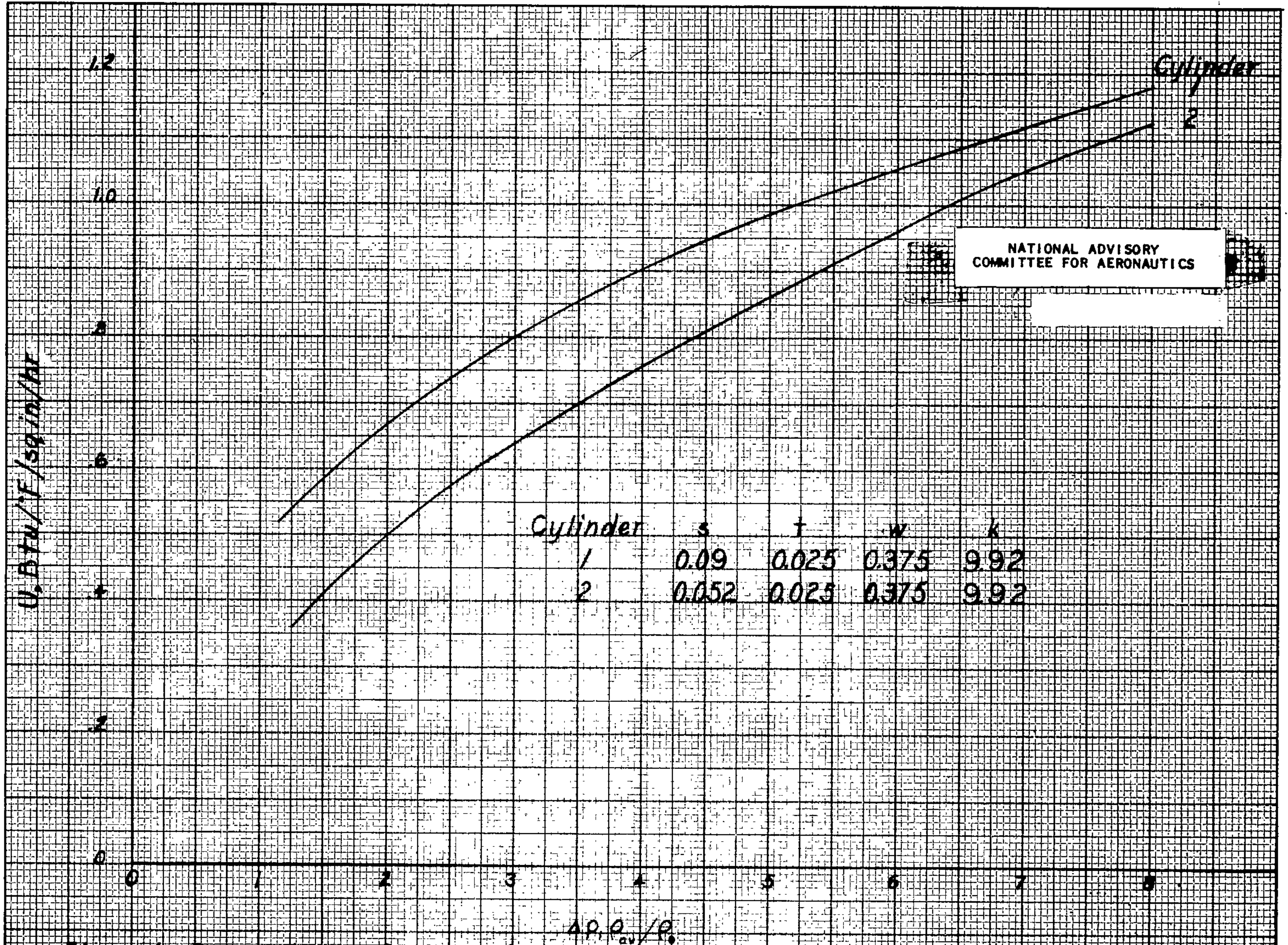
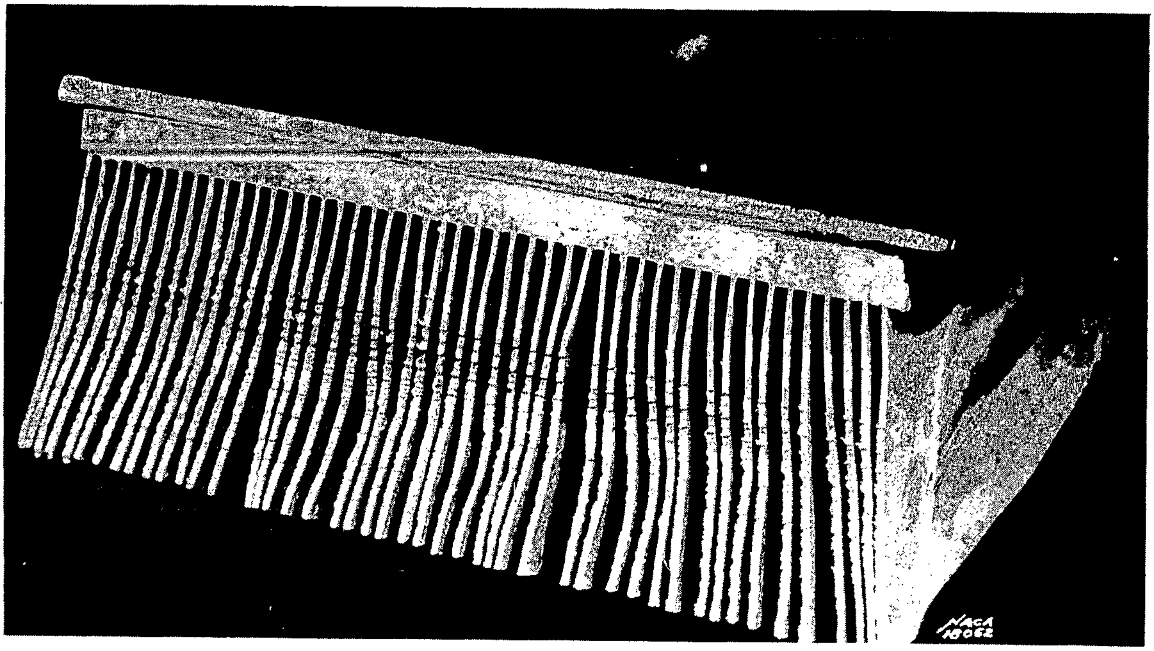


Figure 3.- Comparison of over-all heat-transfer coefficients of test cylinder with calculated coefficients.

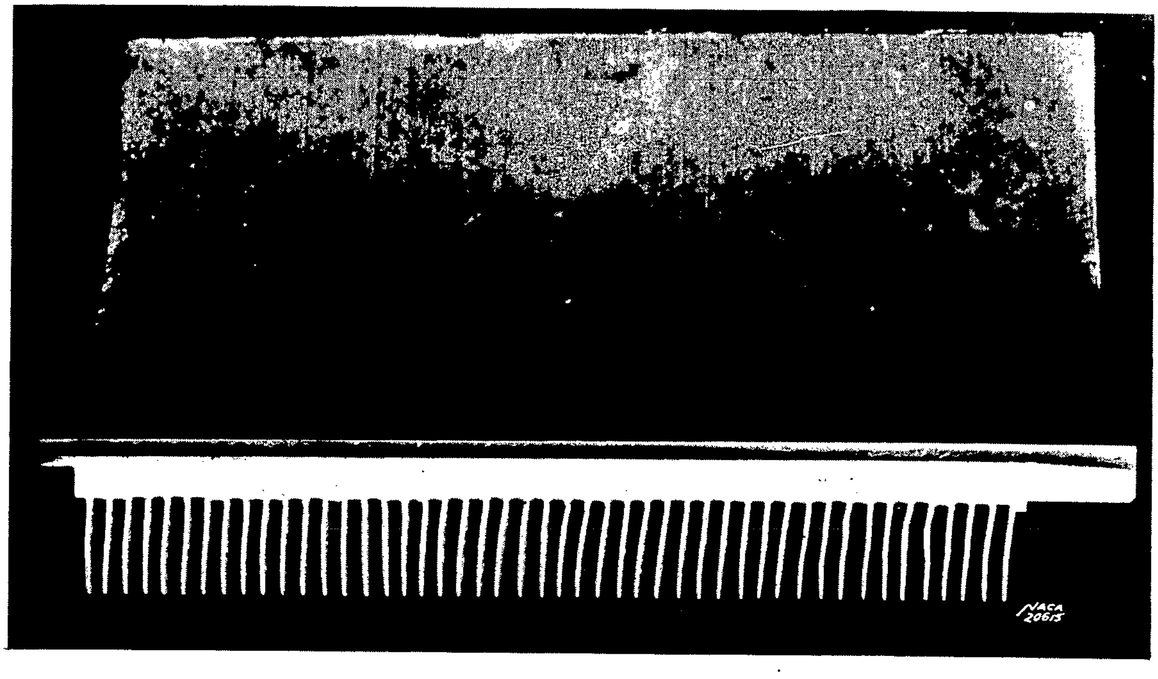


Cylinder	s	t	w	k
1	0.09	0.025	0.375	9.92
2	0.052	0.025	0.375	9.92

Figure 4.- Comparison of over-all heat-transfer coefficients of two aluminum cylinders with aluminum fins.



(a) First cylinder.



(b) Second cylinder.

Figure 5. - Cross sections of cylinders after polishing and etching.