FILE COPY
NO. 1-W

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

May 1941 as
Advance Confidential Report

CYLINDER BARREL COOLING WITH BONDED PREFORMED COPPER FINS

By H. H. Foster and H. H. Ellerbrock, Jr.

Aircraft Engine Research Laboratory
Cleveland, Ohio

FILE COPY
To be returned to
the files of the National
Advisory Committee
for Aeronautics
Washington D. C.

NACA

WASHINGTON

NACA WARTIME REPORTS are reprints of papers originally issued to provide rapid distribution of advance research results to an authorized group requiring them for the war effort. They were previously held under a security status but are now unclassified. Some of these reports were not technically edited. All have been reproduced without change in order to expedite general distribution.

CYLINDER BARREL COOLING WITH BONDED PREFORMED COPPER FINS

By H. H. Foster and H. H. Ellerbrock, Jr.

SUMMARY

Preformed copper fins were furnace-brazed to a steel-cylinder barrel. The barrel was electrically heated and blower-cooled to determine the over-all heat-transfer coefficient. The experimental coefficients, based on the temperature of the steel, were approximately twice as large as the calculated coefficients for a similar steel cylinder with integral fins of the same dimensions.

Improving the thermal bond, which can be accomplished by improving the method of assembly of the fins on the barrel before the brazing, can possibly increase the heat transfer of the barrel 27 percent above the values obtained. Both the copper fin and the steel barrel are annealed by the 1200° F furnace temperature required for brazing. Recent developments of high-frequency induction heating for the brazing operation are being investigated with a view to avoiding the incidental annealing which occurs in furnace brazing of the fins.

INTRODUCTION

The NACA in the past few years has conducted numerous tests on the cooling of finned cylinders. Analyses of the results of these tests indicate that wider and closer spaced fins are required for the modern air-cooled aircraft engine than can be obtained by the usual casting or machining technique.

The preformed fin offers the advantages of practically unlimited fin dimensions and fin spacing as well as a fin material having a higher thermal conductivity than that of the usual integral steel fin. Copper has a thermal conductivity more than 8 times that of steel and more than

$2\frac{1}{4}$ times that of aluminum alloy. The weight of copper finning for equivalent cooling, therefore, compares favorably with that of finning with considerably lighter metals. Copper is easily bonded to steel and its procurement in times of war has usually been easier than that of the lighter metals.

This report presents results of blower-cooling tests of a cylinder barrel with furnace-brazed preformed copper fins. The over-all heat-transfer coefficients were determined and are shown plotted against the theoretical values to obtain an indication of the excellence of the bond between the copper and the steel. A discussion of the advantages of copper fins and of future methods of bonding them to the cylinder is included.

CYLINDER ASSEMBLY

The first barrel was made from a stock Pratt & Whitney forging, roughly machined to an outside diameter approximately that of the root diameter of the fins on a finished "Wasp"-size barrel. Twenty-six fins nearly 2 inches wide and spaced about 1/8 inch apart were assembled on the barrel. They were made from 0.026-inch sheet copper with a flange rolled on the inner diameter to serve as a means of spacing and to afford a large surface for bonding to the barrel (fig. 1). The copper-joint surfaces were cleaned with emery cloth and a pickling fluid. The steel barrel was also thoroughly cleaned with emery cloth and washed with benzine to remove grease; a commercial flux was applied. After the fins were assembled on the barrel a ring of 1/16-inch diameter, low-melting, silver solder was placed around each joint and more flux was added.

The fins, although in one piece, were split to permit of their being spread to go over the thread belt. This split was tacked together at the outer edge of the fins with solder after the rings of solder were in place.

The barrel assembly was electrically furnace-brazed in a hydrogen atmosphere at a maximum temperature of 1200° F. Table I shows a time-temperature record of the barrel while being brazed.

The fins came from the furnace in the annealed state and had lost some of their original rigidity, although they retained their original bright copper color.

A second and a third barrel, not yet tested, were machined like the first except that the outside diameter was of a uniform size above the barrel flange so that it was not necessary to cut the fins at assembly as in the first set-up. The difference in diameter between the barrel and the fin was about 0.005 inch at room temperature. It was found better to have the fins a push-spring fit on the barrel owing to the greater expansion of the copper so that the solder will not run down the barrel and be lost during the time the assembly is in the furnace.

After the fins were assembled a concentric ring of steel was then added for the thread belt and the whole assembly was furnace-brazed as in the first set-up.

The copper used for the fins of the second and third barrel was "oxygen free," a much better grade than that used for the first barrel.

Another method of assembling the fins without cutting them would be the use of the "aero" type thread which permits a uniform size for the outside of the barrel above the barrel flange.

HEAT-TRANSFER TESTS

Test apparatus.- The test 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 prevented by using cylindrical guard rings made of sheet metal and filled with rock wool (fig. 2).

Surface temperatures were obtained at 29 points around the cylinder by means of iron-constantan thermocouples made from No. 40 gage wire. Nine of the thermocouples measured the temperature of the steel barrel every $22\frac{1}{2}^{\circ}$ from front to rear of the cylinder and five measured the temperature at the base of the copper fins.

In order to attach the thermocouples to the steel, 1/8-inch diameter holes were drilled through the copper and solder with a tapered drill until the drill point touched the steel. Then 0.018-inch diameter holes were drilled in the steel and the thermocouples peened in place. The holes were then filled with bakelite varnish. The

thermocouples were attached to the fin base by cutting small 0.010-inch wide slots in the metal and peening the thermocouples in place. Thermocouples were placed on the fins one-third and two-thirds of the distance from base to tip, and on the tip every 45° from front to rear of the cylinder. The thermocouples were soldered to the fins. Thermocouples were distributed over a number of fins so as not to block the air flow in any one fin space. They were shellacked to the fins and brought out through a bakelite tube to a cold junction board as shown in figure 3. An ammeter and a voltmeter were used to measure the electrical input of the cylinder and a potentiometer measured the cylinder temperatures.

Jacket.- The test unit was enclosed in a wood jacket, as shown in figure 3, and air was drawn over the set-up with a Roots blower. The jacket shape and apparatus used for such a test are fully described in references 1 and 2. The jacket fitted tightly against the fin tips and guard rings. Partitions were placed between the guard rings and cylinder (see fig. 3) so that all the air flowing into the jacket would flow over the cylinder. The weight of cooling air 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. A diagrammatical sketch of the apparatus is shown in figure 4.

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 over the cylinder by the free-flow area between the fins.

The experimental heat-transfer coefficients, U, were 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 and the entering-air temperature. Coefficients were determined based on both the temperature of the steel and the bent-over portion of the fins of the cylinder.

Coefficients were also calculated for steel and practically pure copper fins, of the same proportions as those of the test cylinder, cast integrally. These coefficients were based on data determined from tests of a large number of cylinders (reference 3). The methods of testing, together with a more detailed description of the methods of calculating the coefficients, are described in references 1, 2, 4, and 5.

DISCUSSION

Figure 5 shows the results of the tests on the present cylinder and calculated coefficients based on test results of other cylinders. The coefficients based on the temperature difference of the copper at the fin root and the cooling air are approximately 9 percent lower than the calculated coefficients for practically pure copper. About 5 percent of this difference can be due to variation of the test data; the remaining difference may be due to difference in purity of the copper. The experimental coefficients based on the steel temperatures are approximately 14 percent lower than the experimental coefficients based on the copper temperatures at the fin root, indicating that the thermal bond between the copper fins and the steel barrel is not perfect; that is, a temperature drop occurs across the joint. Improving the bond and increasing the purity of the metal can possibly increase the heat transfer of the cylinder 27 percent. However, the experimental coefficients of the test cylinder based on the steel temperature are approximately twice as great as the calculated coefficients for a steel cylinder with steel fins of the same dimensions, even with an imperfect thermal bond.

In all the tests the over-all heat-transfer coefficient showed that the bond between the copper fins and the steel cylinder was imperfect. This condition was anticipated because in drilling holes at the flange of the fin for inserting the thermocouples, occasional voids were encountered. When a condition of this kind was experienced, the thermocouple was placed adjacent to the void but far enough away to be unaffected by this condition. In order to avoid an imperfect bond, leakage of the brazing material past the fins should be eliminated so that the space between the fins and the barrel is completely filled. This can be accomplished by making the fins a tighter fit on the barrel at assembly.

Future work on the adaptation of preformed copper fins to steel cylinders will include an investigation of the merits of high-frequency induction heating for brazing. This process will give a good bond and may avoid annealing the copper fin and the steel-cylinder barrel. Simultaneous induction hardening of the barrel and brazing of the fins would afford a speedy production process.

A copper muff with extruded integral fins has also

been suggested as a method of barrel cooling worthy of investigation. The extrusion process is now used in making fins on cooling coils for air-conditioning equipment and if it can be applied to the fin sizes required for air-cooled engine cylinders it may have some possibilities from the standpoint of production.

Engine tests have not yet been made to determine the effect of engine vibration and other operating conditions on the copper fin. It may be necessary to support the fins at the outer edge, particularly where very wide fins are required to obtain the proper cooling. Support for the fin could be obtained by soldering or brazing the fin tips to the jacket which directs the air flow across the fins.

A comparison of the relative cooling obtained with copper, aluminum, and steel fins is shown in figure 6. When compared on a weight basis, it can be seen that the higher thermal conductivity of the copper more than offsets its greater weight.

The large increase in over-all heat-transfer coefficient obtained with the bonded preformed copper fin should permit an increase in the specific outputs of aircraft engines of two to three times those permissible with present-day integral steel fins without exceeding barrel-cooling limits.

CONCLUSIONS

1. The experimental heat-transfer coefficient of a steel-cylinder barrel with bonded preformed copper fins was more than twice that of the calculated coefficient of a similar barrel with integral steel fins of equal dimensions and spacing.

2. The preformed copper fin can be easily bonded to a steel-cylinder barrel. Owing to its high thermal conductivity factor, it compares favorably with any of the lighter fin materials on a fin weight-cooling basis.

3. The use of bonded preformed copper fins should permit an increase in the specific outputs of aircraft engines of two to three times those permissible with present-day integral steel fins without exceeding barrel-cooling limits.

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

REFERENCES

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

2. Rollin, Vern G., and Ellerbrock, Herman H., Jr.: Pressure Drop across Finned Cylinder Enclosed in a Jacket. NACA TN No. 621, 1937.

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

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

5. Schey, Oscar W., and Rollin, Vern G.: The Effect of Baffles on the Temperature Distribution and Heat-Transfer Coefficients of Finned Cylinders. NACA Rep. No. 511, 1934.

TABLE I

Atmosphere	Hydrogen				
Time	Temperatures °C				
	Cylinder barrel thermocouples			Furnace	
	No. 1	No. 3	No. 5	Top	Bottom
9:30				750	750
9:35	----	----	225	750	750
9:40	280	230	345	685	635
9:45	417	384	445	665	590
9:50	495	471	520	635	615
9:55	560	544	575	640	655
10:00	575	573	590	625	625
10:05	590	590	595	615	615
10:10	618	618	630	635	638
10:15	628	628	640	645	635
10:20	630	630	640	620	610
10:25	637	637	640	615	610
10:30	652	652	660	640	645

At 10:30, work sent to cooler.

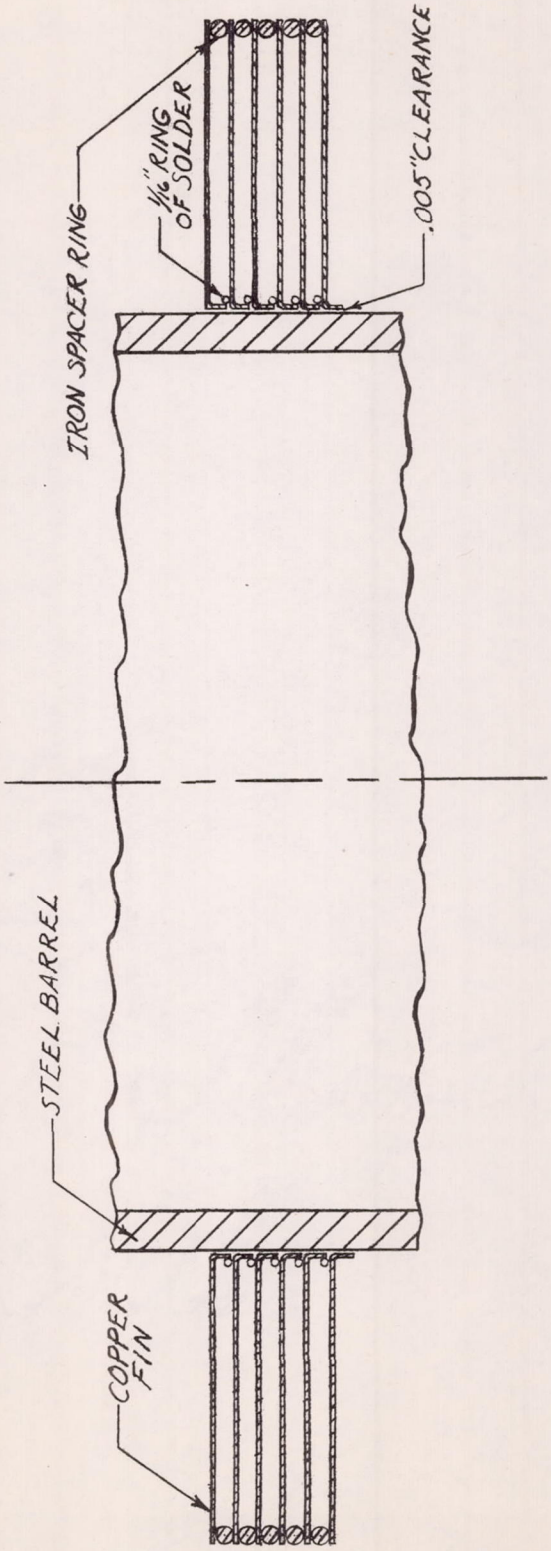


Figure 1.- Fin and cylinder assembly before brazing.

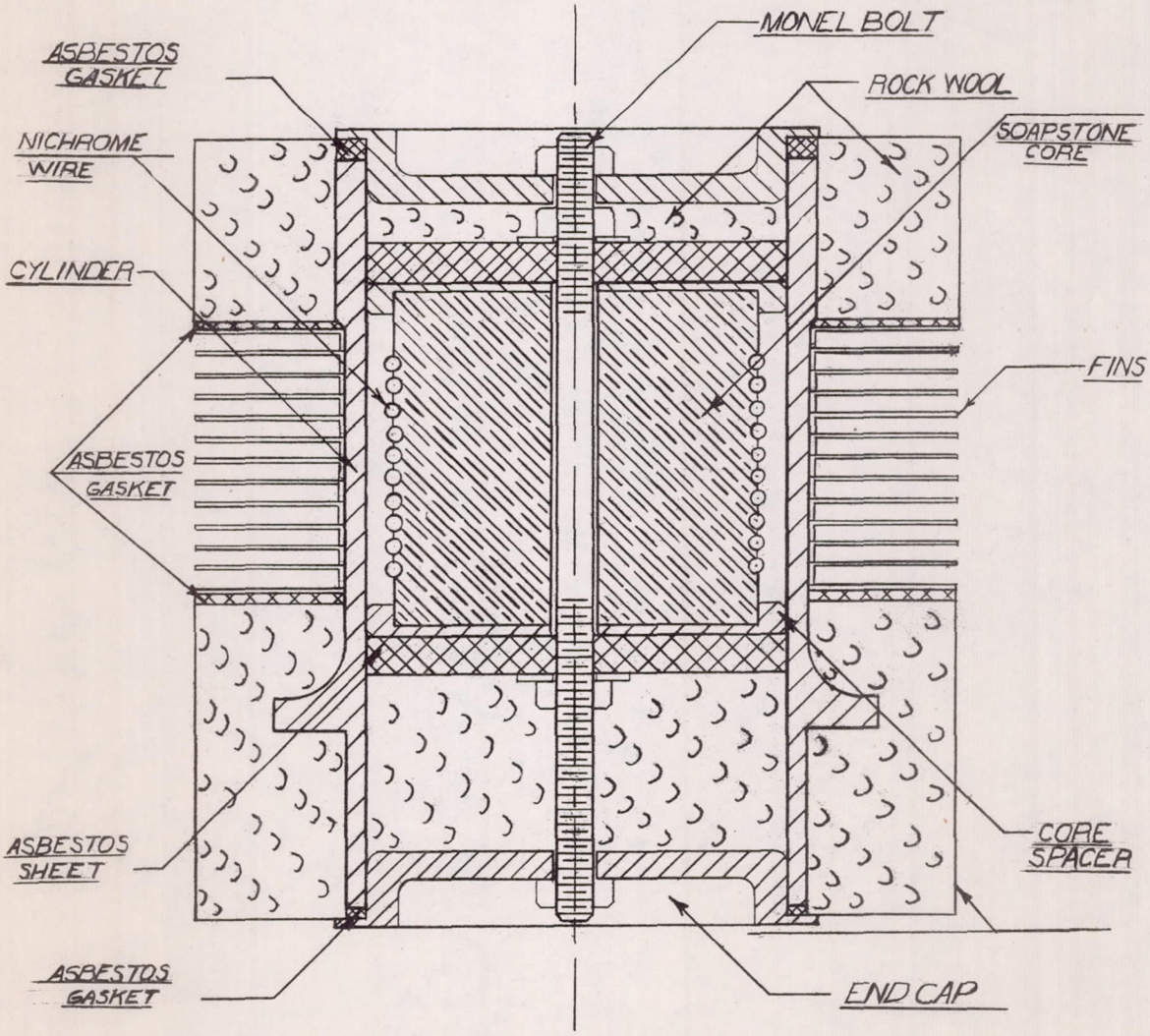


FIG. 2 - DETAILS OF CONSTRUCTION OF TEST UNIT

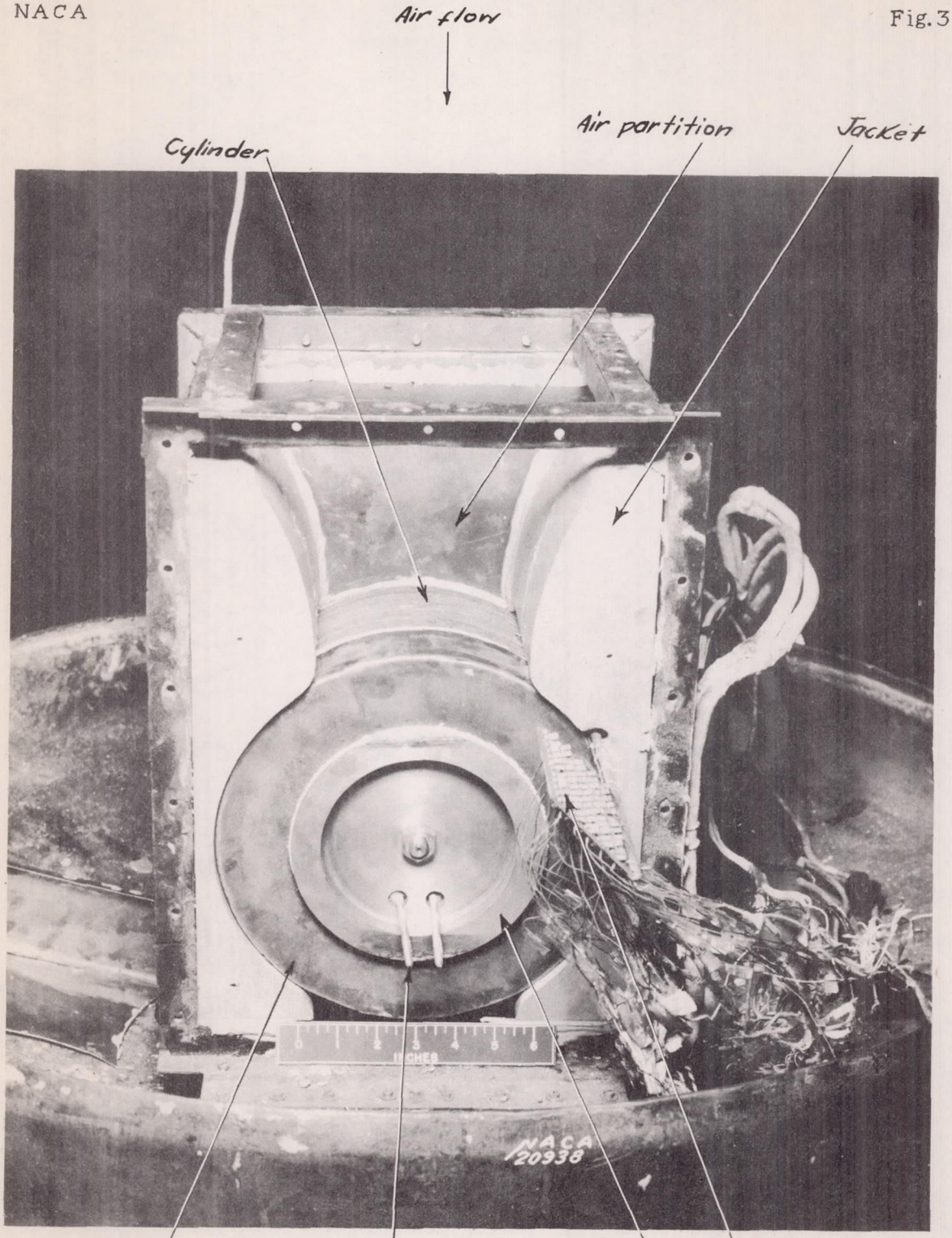


Figure 3 - Test-unit set-up with jacket.

#26

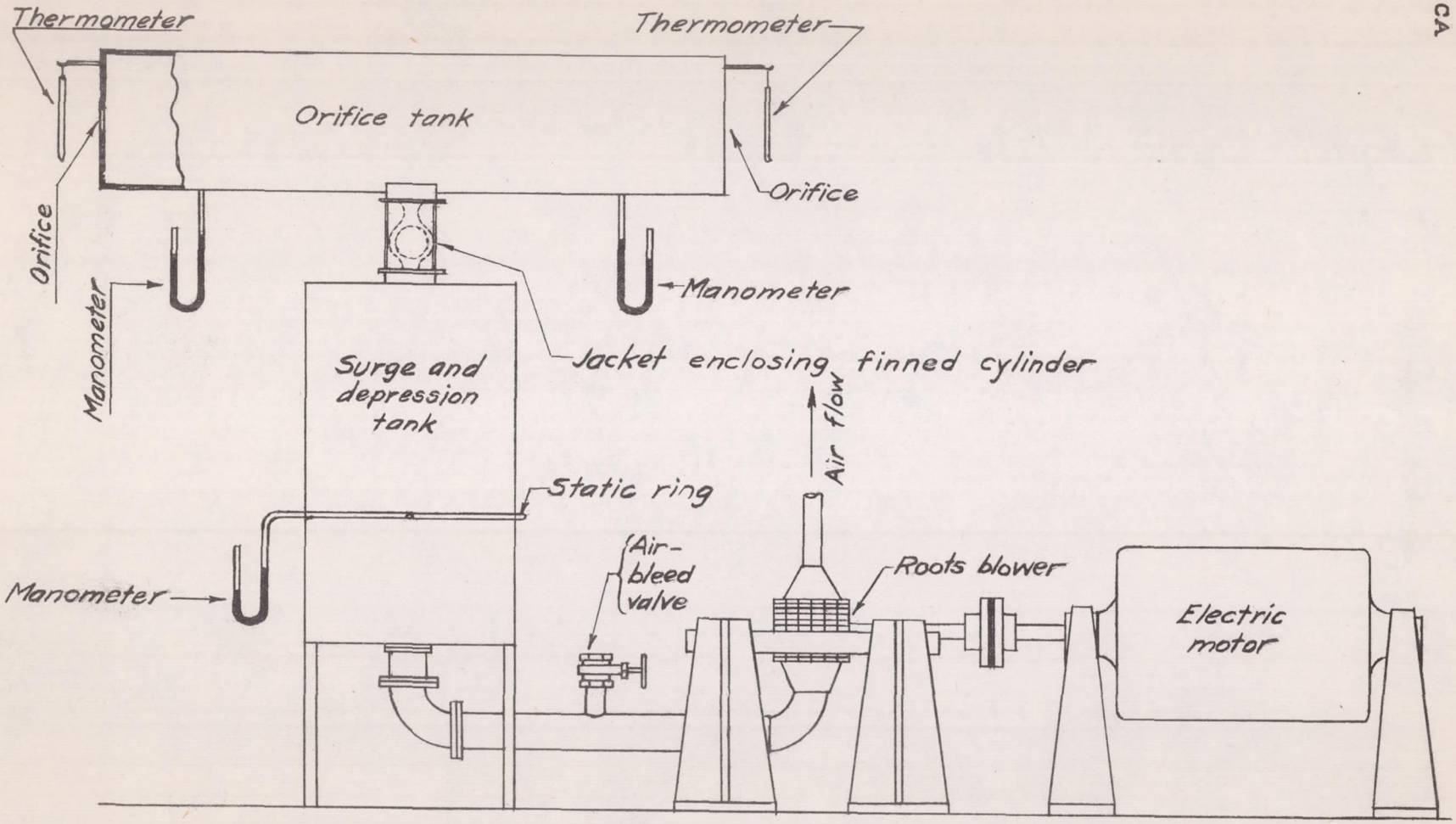
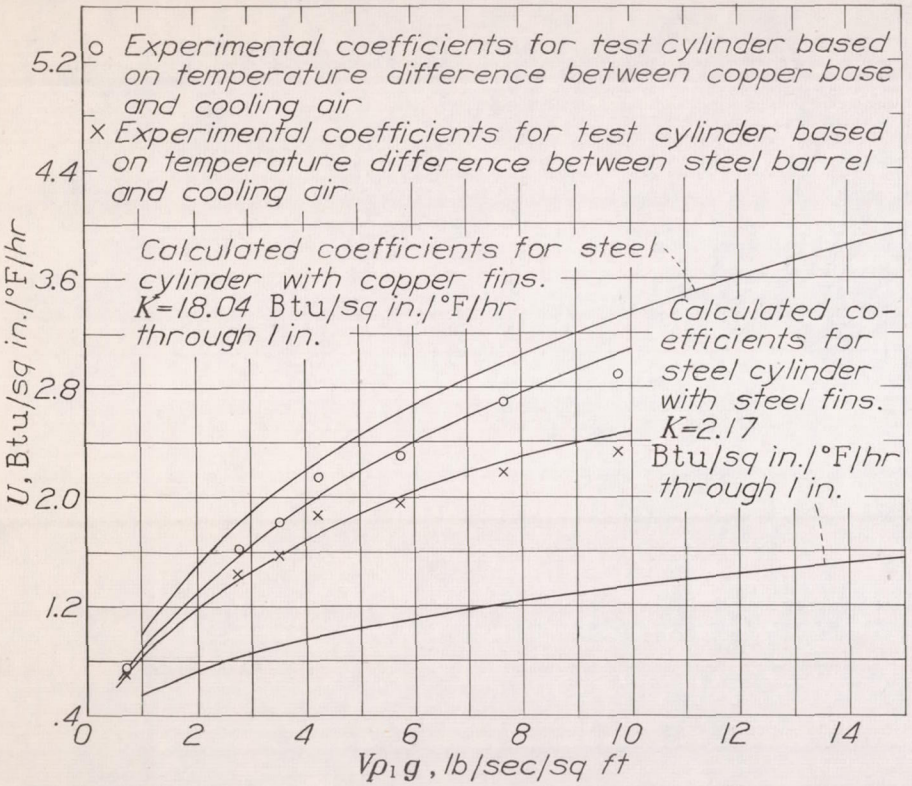
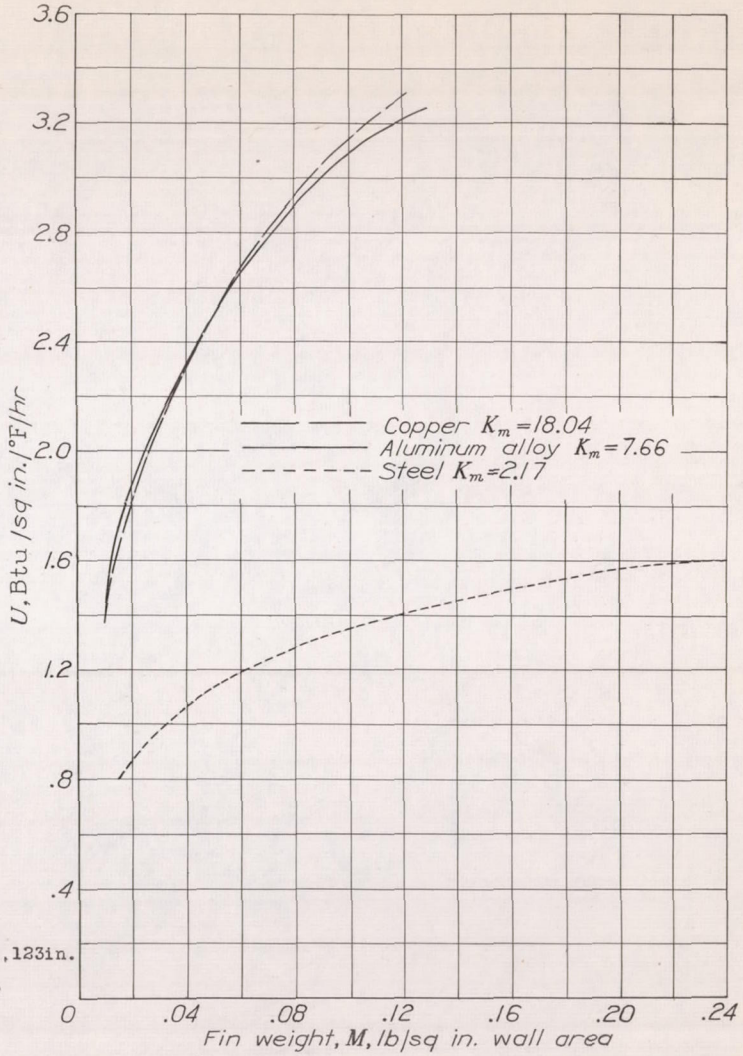


Figure 4.- Diagrammatic set-up of test equipment.



Cylinder diameter, 6.13 in.; Fin width, 1.92 in.; Fin thickness, .026 in.; Fin space, .123 in.

Figure 5.- Comparison of over-all heat-transfer coefficients of test cylinder with calculated coefficients.



Legend:
K_m, thermal conductivity coefficient

Figure 6.- Comparison of the over-all heat-transfer coefficient for a given fin weight for copper, aluminum, and steel.