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INVESTIGATION OF METHODS OF REDUCING THE TEMPERATURE VARIATION AMONG CYLINDERS ON AIR-COOLED AIRCRAFT ENGINES

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WASHINGTON

MEMORANDUM REPORT

INVESTIGATION OF METHODS OF REDUCING THE TEMPERATURE VARIATION AMONG CYLINDERS ON AIR-COOLED AIRCRAFT ENGINES

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SUMMARY

Tests have been made to determine methods for reducing the temperatures of the hot cylinders on air-cooled aircraft engines. A Pratt & Whitney R-1830-43, 14-cylinder engine was used for the tests.

Reductions of 30° F to 35° F in the cylinder-head and barrel temperatures were obtained by the use of ducts directing cooling air upon the rear of the cylinders. Increasing the cylinder fin area by welding additional lengths of metal to the existing fins resulted in temperature reductions of about 26° F. Baffle modifications which included enlarging the inlet gaps, extending the baffles farther to the rear of the cylinder, adding a diffuser at the baffle outlet, and providing separate ducts to the hot parts of the cylinder, resulted in head-temperature reductions of as much as 50° F. In addition, large reductions in the temperatures of individual cylinders were obtained by injecting additional fuel ahead of the cylinder intake ports.

It appears that the pressure drop required to cool many air-cooled engines may be considerably reduced by decreasing the temperatures of the individual hot cylinders through the use of methods similar to those tested.

INTRODUCTION

The head and barrel temperatures of radial aircraft engines vary considerably from cylinder to cylinder. Frequently a few cylinders have temperatures as much as 60° F above the average and are referred to as the "hot" cylinders of the engine. These temperature differences aggravate the cooling problem because, if the hot cylinders are to be cooled satisfactorily, the other cylinders must be overcooled. In some cases the pressure drop required to cool the engine may be decreased as much as 40 percent by reducing the temperatures of the hot cylinders to the average cylinder temperature.

Tests have been made to determine the effectiveness of several methods for reducing the temperatures of the hot cylinders on air-cooled aircraft engines. This investigation includes: (1) directing cooling air upon the rear of the cylinders, (2) increasing the fuel-air ratio F/A of separate cylinders by injecting additional fuel just ahead of the intake ports, (3) increasing the cooling area of the cylinders by attaching additional lengths of metal to the existing fins, and (4) modifying the cylinder baffles. The tests were conducted with a Pratt & Whitney R-1830-43 engine installed in a wing nacelle.

APPARATUS AND TESTS

The P. & W. R-1830-43 engine is a 14-cylinder, two-row, air-cooled aircraft engine with a normal rating of 1100 horsepower and a military rating of 1200 horsepower. The engine was equipped with a Stromberg PD-12F2-14 injection-type carburetor. The nacelle was mounted on supports as shown in figure 1. A propeller-speed fan and large-chord cowl flaps were used to supply cooling air for the engine.

In addition to measurements of the temperature of each rear-spark-plug gasket and cylinder flange, measurements were made of the temperature at 16 other points over the head and barrel of one of the rear cylinders. Fuel-air ratios for individual cylinders were determined from exhaust-gas analyses. The average engine fuel-air ratio was checked with measurements of engine air and fuel consumption.

Tests were made with small ducts directing cooling air upon the rear of cylinders 13 and 14, which were chosen because of their accessibility. The inlet of the duct for cylinder 13 was located in the intercooler cooling-air duct with a scoop to utilize the available total pressure and the inlet of the duct for cylinder 14 was located between the cylinder rocker boxes, as shown in figure 2. The duct outlets were 1 inch from the cylinders and directed approximately the same amount of cooling air on the rear of the barrels and the heads. The duct outlets were 1 inch wide and were located approximately in the center of the baffle outlets. The baffle outlets on the P. & W. R-1830-43 engine vary from 3 to 5 inches in width; the outlets on the rear cylinders are somewhat wider than on the front cylinders. Total- and static-pressure tubes were used to measure the air flow through the ducts. In order to insure that the spark-plug-gasket and cylinder-flange thermocouples would give reliable indications of the temperature reductions at points on the cylinder not being directly cooled by this air, the areas immediately around the thermocouples were shielded from the cooling air by small tabs extending from the duct outlets to the cylinder walls (fig. 2).

Tests were made with separate enrichment of the mixture to cylinders 1 and 10. The additional fuel was fed in a continuous spray through the primer fittings, which are located just ahead of the cylinder intake ports. The amount was manually adjusted with a needle valve. A small rotameter was used to measure the amount of fuel injected.

Three methods were used to attach additional cooling area to the cylinders: welding, clipping, and bolting. Extensions were welded to the existing fins on the top of the cylinder head (figs. 3 to 6). The total added cooling area amounted to approximately 382 square inches. The top baffle used with these extensions is shown in figure 6. Fin extensions were also clipped to the existing fins on the top of the cylinder head as shown in figures 7 to 9. The added cooling area in this case was about the same as with the welded extensions. The ends of the clipped extensions were riveted to a plate that served as the head baffle. The ends of the fins were scraped to obtain a smooth surface and uniform thickness before the extensions were installed. Tests were made with the joint plain and with the connecting parts coated with a mixture of aluminum powder and black lacquer in an attempt to improve the thermal bond. Tests were also made of copper fin extensions wedged and bolted to the rear of the cylinder head as shown in figures 5 and 10. The added fin area was about 268 square inches. For this test the cylinder baffles extended farther to the rear of the cylinder, as shown in figures 6 and 10.

Tests were made of the following types of baffle modification:

(1) Enlargement of the baffle inlets and extension of the baffles farther around to the rear of the cylinders

(2) Addition of diffusers at the baffle outlets to recover part of the kinetic energy of the cooling air and to increase the cooling-air flow

(3) Provision of ducts incorporated in the baffles to carry unheated air to the hottest parts of the head (fig. 11 shows one such baffle tested)

In addition, completely revised baffles combining these three modifications were installed on the rear cylinder of the P. & W. R-1830-43 engine. These baffles are compared with the original baffles in figures 12 to 14. Additional views of the revised baffles are shown in figure 15.

Most of the changes were tested on only one or two cylinders of the engine and were evaluated by comparing engine temperature patterns obtained with and without the changes. In order to reduce the error due to erratic variations in the temperature pattern, five to eight tests were made of each modification. These tests were made over a range of engine power from low-cruising to normal.

RESULTS AND DISCUSSION

The temperature data have been corrected for variations in atmospheric conditions and for small variations in engine operating conditions in order that the results obtained for the various modifications may be compared directly with the results obtained for the cylinder or engine in its original condition.

Cooling-air ducts. - The effect of the cooling-air ducts is shown in figures 16 to 18. The changes in the temperatures of the rear-spark-plug gasket and the cylinder flange are indicated in the figures by the symbol Δt. At 97 percent normal power (fig. 16) with both ducts in place, the air flow through the duct to cylinder 13 was 86 pounds per hour. This flow resulted in a reduction of 36° F in the head temperature and of 29° F in the barrel temperature. The air flow through the ducts on cylinder 14 was 54 pounds per hour, and the head and barrel temperatures were reduced about 7° F and 2° F, respectively.

The temperature reductions at 58 percent and 48 percent normal power (figs. 17 and 18) are somewhat less than at 97 percent normal power. When the air flow through the duct to cylinder 13 was reduced to about three-fourths its original quantity by blocking off part of the inlet, the temperature reductions were between one-half and two-thirds their original values. The higher air flow through the duct to cylinder 13 is due to the total pressure built up in the intercooler cooling duct by the propeller operation. Because the pressure drop across the engine was small

(3 to 4 in. of water) during these tests, the flow through the duct on cylinder 14 was low. In flight, the pressure drop across the engine is considerably higher (8 to 15 in. of water) and a duct similar to the one used on cylinder 14 might be considerably more effective than indicated by these tests.

The effect of the cooling ducts upon the temperatures at the front of the cylinders was not determined because reductions in these temperatures are considered less important than reductions in the temperatures at the rear of the cylinders. The temperatures at the front of the cylinders are more than 100° F below the temperatures at the rear of the cylinders and probably have comparatively little effect in inducing preignition and detonation or in increasing the rate of wear of the engine.

Mixture-enriching tests. - Inasmuch as the temperature of the combustion gases in an engine cylinder decreases as the mixture is enriched above a fuel-air ratio of 0.07, cylinder-head temperatures may readily be reduced by increasing the fuel-air ratio. As the specific fuel consumption increases rapidly with increasing fuel-air ratio, however, enriching the mixture of the entire engine to improve cylinder cooling is generally undesirable except for short-period operation. A few cylinders may be cooled in this manner with a relatively small increase in engine fuel consumption.

The results of the injection of additional gasoline into the cylinder primer fittings are shown in figures 19 to 22. On the cylinders with the enriched mixtures, the head temperatures were reduced 14° F to 44° F with little change in barrel temperatures. In each test, fuel-flow and exhaust-gas measurements showed that all the fuel injected did not pass through the cylinder for which it was intended. Because of the pulsating and turbulent flow in the intake pipes, some of the fuel was evidently carried back into the blower section. Exhaust-gas analysis showed a slight general enriching of the mixtures throughout the entire engine and only from 50 to 80 percent of the admitted fuel was accounted for in the exhaust of the cylinder for which the fuel was intended.

In practice, if the fuel were injected in a continuous spray, as in the present tests, it would probably be advisable to compensate for the resulting general enrichment by decreasing the amount of fuel delivered by the carburetor. If the carburetor were so adjusted, the head temperatures of three cylinders on a P. & W. R-1830-43 engine could be reduced an average of 20° F at cruising powers ($\frac{F}{A} = 0.068$) with an increase in specific fuel consumption of about 3 percent. Without an adjustment, the fuel consumption would be increased approximately 5 percent.

Injecting additional gasoline ahead of the intake ports of hot cylinders would be particularly useful when the temperature differences existing between cylinders are primarily due to poor mixture distribution. For this case, the differences in cylinder power output as well as the differences in temperature would be reduced.

Additional cooling area. - Table I gives a comparison of cylinder temperatures obtained with the original cylinder and with the cylinder with the three types of fin extension. Results are shown for two power conditions: 65 percent normal power and 100 percent normal power.

The welded fin extensions (figs. 3 to 6) reduced the temperature of the rear-spark-plug gasket about 29° F at 65 percent normal power and about 22° F at 100 percent normal power; whereas the clipped-on extensions (figs. 7 to 9) reduced the head temperature only 10° F and 6° F for the two power conditions. Inasmuch as the increase in fin area was the same in each case, the smaller temperature reduction with the clipped-on extensions must be due to a poor thermal bond between the original fin and the clipped-on extensions. The addition of a mixture of aluminum powder and black lacquer between the connecting parts of the fins and the extensions showed no improvement in the thermal conductance.

The addition of copper fins bolted and wedged to the rear of the cylinder head gave no substantial reduction in temperatures. The ineffectiveness of these fins may be attributed to the higher temperature of the cooling air at the rear of the cylinder, a poor thermal bond at the bolted and wedged joint, and higher resistance to the cooling air resulting in reduced air flow.

Baffle modifications. - Temperature data obtained from the tests of the various baffle modifications are given in table II. Important temperature reductions were obtained with several of the configurations tested. Reductions of 34° F in the temperature of the rear-spark-plug gasket at 65 percent normal power and of 25° F at 100 percent normal power were obtained by enlarging the baffle-inlet gap to 5/8 inch, extending the baffle farther to the rear of the cylinder, and providing a radius of curvature of 1/2 inch at the outlet (condition 5 in table II). As shown for condition 7, temperature reductions of 19° F and 15° F were obtained at 65 percent and 100 percent normal power, respectively, by continuing the baffle farther to the rear of the cylinder and adding a short diffuser.

Reductions in temperature of 9° F and 12° F at 65 percent and 100 percent normal power, respectively, were obtained with a top head baffle having a separate duct carrying cooling air to the rear of the fins (condition 9). The inlet to this duct is shown in figures 12 to 15. As shown in figures 12 and 13, fingers projected from the baffle into the fin passages at the top of the head to divert the heated air that flowed over the front fins out of the rear fin passages. A side baffle incorporating a similar duct (fig. 11) gave temperature reductions of 20° F at 65 percent normal power and 18° F at 100 percent normal power (condition 10). With both these new baffles on the cylinder, temperature reductions of 31° F and 35° F were obtained (condition 11).

The completely revised baffles (figs. 12 to 15) combining many of the separate modifications tested, when installed on single cylinders of the engine, gave temperature reductions of about 50° F (condition 12). Tests with the revised baffles installed on all cylinders are reported in reference 1.

As first tested, the temperature of the exhaust-valve guide was somewhat higher with the revised baffles than with the original baffles although the temperatures at all other hot points on the cylinder were reduced (reference 1). This increase in the temperature of the exhaust-valve guide was found to be due to a restriction at the baffle outlet on the exhaust side of the cylinder below the rocker box, as indicated by the arrow labeled "Restricted outlet" in figure 13(b). The temperatures at various points around cylinder 1 with the restriction removed are shown in figures 23 and 24. It will be noted that substantial reductions have been obtained in the temperatures at the hotter parts of the cylinder. The temperature at nearly every point measured over the combustion chamber has been reduced. The single exception was a comparatively cool point located toward the front of the cylinder. The temperatures at several points on the front and sides of the cylinder head were increased slightly.

The temperatures of the rear center of the barrel and cylinder flange were reduced 10° F to 15° F whereas the temperature of the front of the barrel was increased about 15° F. Inasmuch as the temperatures at the front of the cylinder are so much lower than the temperatures at the rear of the cylinder, the increases in the temperatures on the front are not considered particularly undesirable.

Further reductions in exhaust-valve-guide temperature of about 5° F were obtained by increasing the gap between the fins and baffles, where the fins are short, to eliminate the restriction at that point and by cutting a hole in the side of the baffle to provide an outlet for the cooling air passing between the fins at the front of the rocker box. A sketch of these modifications is given in figure 25.

Application. - It will be noted by reference to the temperature patterns shown in figures 16 to 22 that, by cooling the heads of cylinders 1, 3, and 13, the maximum head temperature of the engine could be greatly reduced at both normal and cruising powers. Similarly, on most other air-cooled engines considerable improvements in cooling may be obtained by reducing the temperatures of a few hot cylinders. On certain large engines, however, the highest temperatures on the engine do not remain fixed but vary from cylinder to cylinder with changes in power output. In such cases, improvements in engine performance can be achieved by increasing the cooling of those cylinders that are the hot cylinders at the critical cooling conditions - namely, normal rated power or maximum cruising power.

CONCLUSIONS

In tests with a P. & W. R-1830-43 air-cooled engine to determine the effectiveness of several methods for reducing the temperatures of the hot cylinders, the following results were obtained:

1. The cylinder-head and barrel temperatures were reduced 30° F to 35° F by the installation of individual air ducts directing cooling air upon the rear of the cylinder. This method can be used advantageously to cool hot cylinders.

2. Additional fuel may be supplied to a few hot cylinders to reduce their head temperatures with comparatively small increases in engine fuel consumption. The enriching may be accomplished by admitting additional fuel ahead of the intake ports.

3. Extensions welded to the fins on the head of a cylinder reduced the temperature at the rear-spark-plug gasket 26° F. Clipping the extensions to the fins was less effective, as this method reduced the head temperature only 8° F.

4. Baffle modifications - which included enlarging the inlet gaps, extending the baffles farther to the rear of the cylinder, adding a diffuser at the baffle outlet, and providing separate ducts to the hot parts of the cylinder - resulted in head-temperature reductions of as much as 50° F.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 19, 1943.

REFERENCE

1. Silverstein, Abe, and Kinghorn, George F.: Improved Baffle Designs for Air-Cooled Engine Cylinders. NACA ARR No. 3H16, 1943.

TABLE I

EFFECT OF DIFFERENT FIN EXTENSIONS

ON CYLINDER-HEAD TEMPERATURES

Condition	65 percent normal power		100 percent normal power	
	Temperature (°F)	Temperature drop (°F)	Temperature (°F)	Temperature drop (°F)
Original	428	--	426	--
Fins welded on top of cylinder head (figs. 3 to 5)	399	29	404	22
Fins clipped on top of cylinder head (plain joint, figs. 7 to 9)	418	10	420	6
Fins bolted on back of cylinder head (figs. 5, 6, and 10	425	3	424	2

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TABLE II.- EFFECT OF BAFFLE MODIFICATIONS ON CYLINDER-HEAD TEMPERATURES.

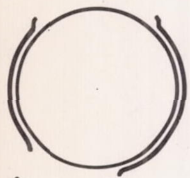
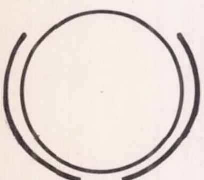
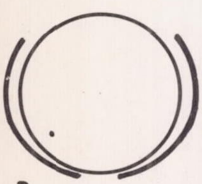
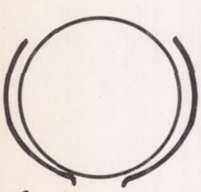
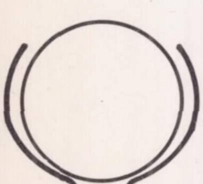
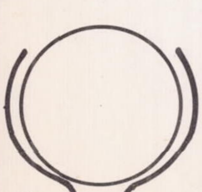
Condition	65 percent normal power		100 percent normal power	
	Temperature (deg F)	Temperature drop (deg F)	Temperature (deg F)	Temperature drop (deg F)
 1 Original baffle; outlet gap, $\frac{3}{16}$"; inlet gap, $\frac{3}{16}$"; outlet width, 5".	451		410	
 2 Baffle opened up; outlet gap, $\frac{5}{16}$"; inlet gap, $\frac{5}{8}$"; baffle extended farther to rear; no outlet radius; outlet width, 2".	446	5	–	–
 3 Baffle opened up; outlet gap, $\frac{1}{16}$"; inlet gap, $\frac{5}{8}$"; baffle extended farther to rear; no outlet radius; outlet width, 2".	434	17	395	15
 4 Baffle opened up; outlet gap, $\frac{1}{16}$"; inlet gap, $\frac{5}{8}$"; baffle extended farther to rear; outlet radius, $\frac{1}{4}$"; outlet width, $2\frac{1}{4}$".	419	32	384	26
 5 Baffle opened up; outlet gap, $\frac{1}{16}$"; inlet gap, $\frac{5}{8}$"; baffle extended farther to rear; outlet radius, $\frac{1}{2}$"; outlet width, $2\frac{5}{8}$".	417	34	385	25
 6 Baffle opened up; outlet gap, $\frac{1}{16}$"; inlet gap, $\frac{5}{8}$"; baffle extended farther to rear; outlet radius, $\frac{3}{4}$"; outlet width, $2\frac{3}{4}$".	432	19	–	–

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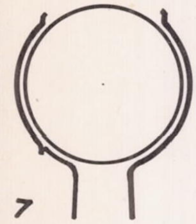
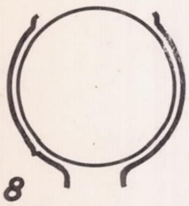
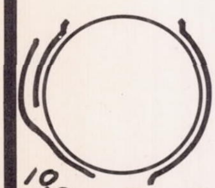
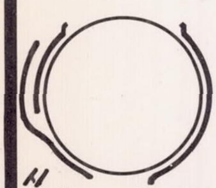
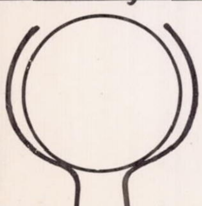
TABLE II.- CONTINUED

Condition		65 percent normal power		100 percent normal power	
		Temperature (deg F)	Temperature drop (deg F)	Temperature (deg F)	Temperature drop (deg F)
 7	Original baffle with outlet diffuser; outlet gap, $\frac{3}{16}$"; inlet gap, $\frac{3}{16}$"; outlet width, $2\frac{3}{4}$"; outlet radius, $1\frac{1}{4}$"; diffuser length, 3."	432	19	395	15
 8	Original baffle with outlet diffuser; outlet gap, $\frac{3}{16}$"; inlet gap, $\frac{3}{16}$"; outlet width, $2\frac{3}{4}$"; outlet radius, $1\frac{1}{4}$"; diffuser length, 1."	439	12	403	7
(See figs. 12, 13, and 15.) 9	Original side baffle; separate duct in top baffle directing cooling air to rear half of cylinder head.	442	9	398	12
 10 (See fig. 11.)	Separate duct on exhaust side of cylinder-head side baffle. Intake side same as original side baffle. Original top baffle.	431	20	392	18
 11 (See fig. 11.)	Separate duct on exhaust side of cylinder-head side baffle. Intake side same as original side baffle. Separate duct in top baffle.	420	31	375	35
 12	Final revised baffle: outlet gap, 0"; inlet gap, $\frac{5}{8}$"; outlet width, $2\frac{1}{4}$"; outlet radius, $\frac{3}{4}$"; diffuser length, $2\frac{1}{4}$". Separate duct in top baffle.	402	49	358	52

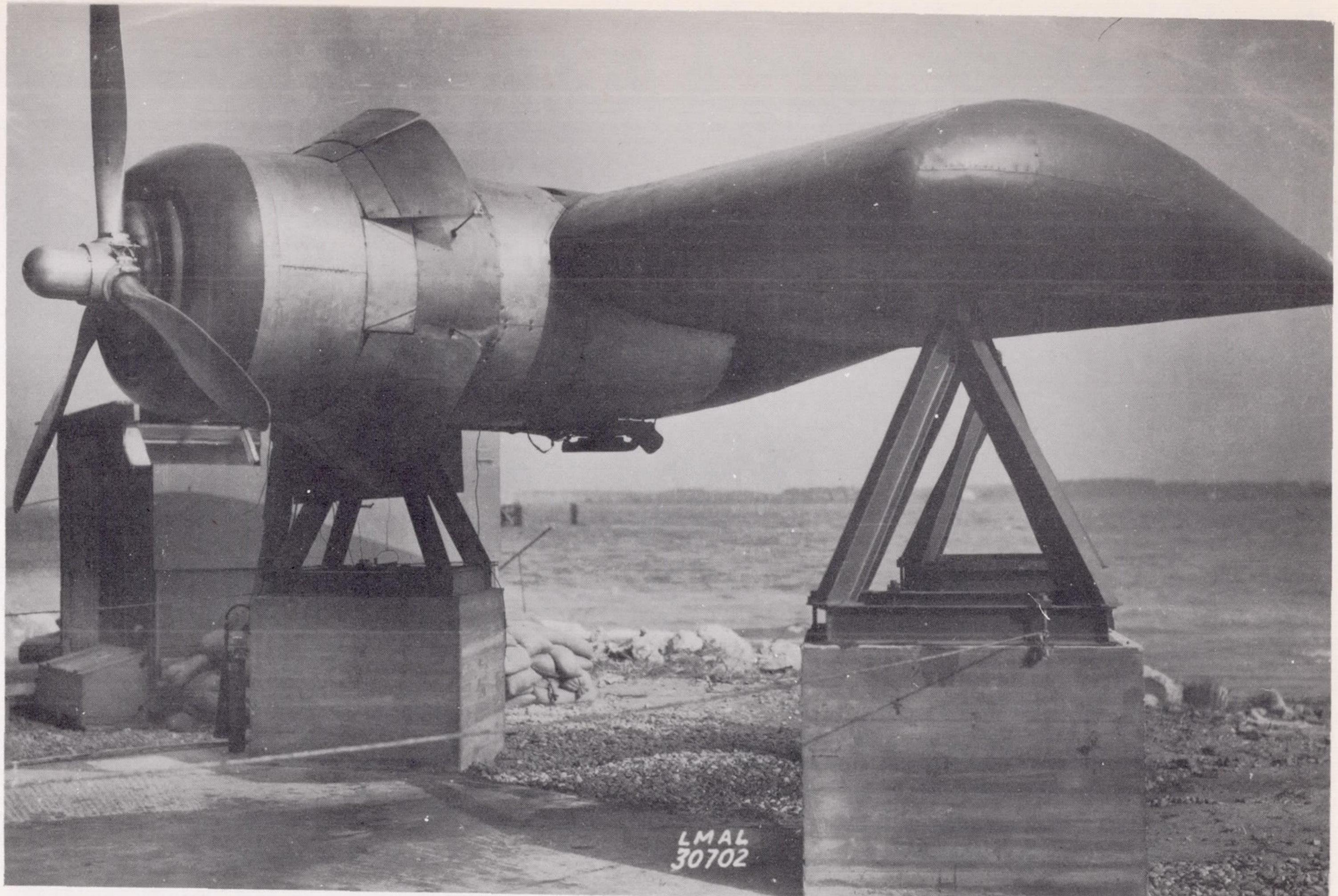
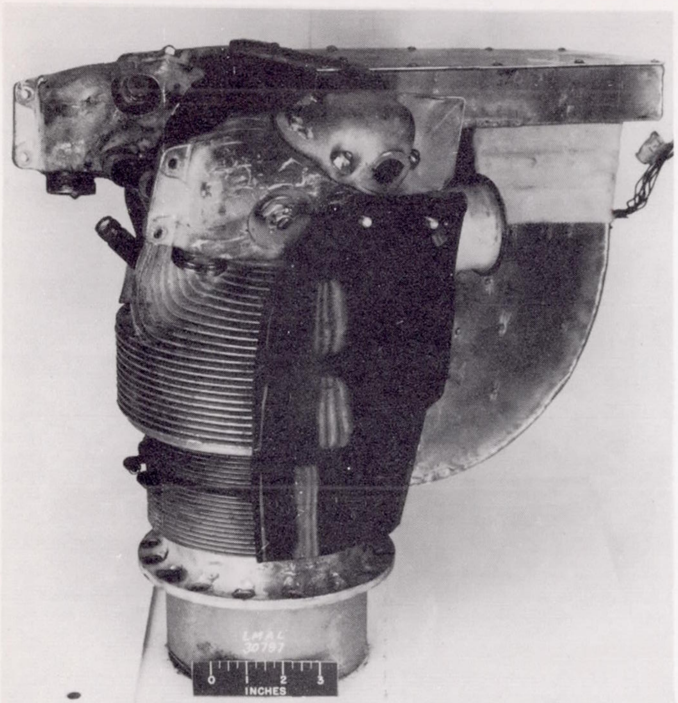
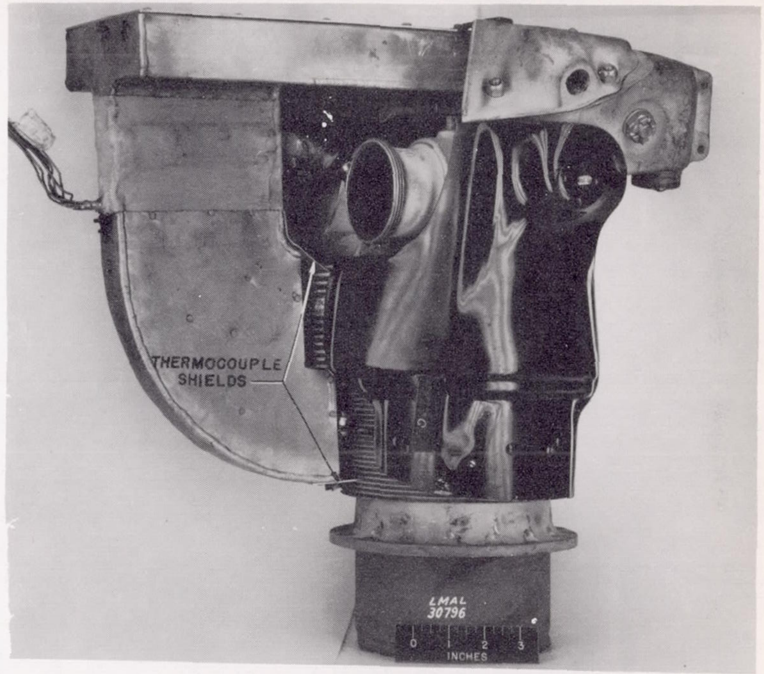


Figure 1.- View of engine nacelle as set up for the tests.



(a) Three-quarter front view.



(b) Three-quarter rear view.

Figure 2.- Cooling-air duct installed on cylinder 14.

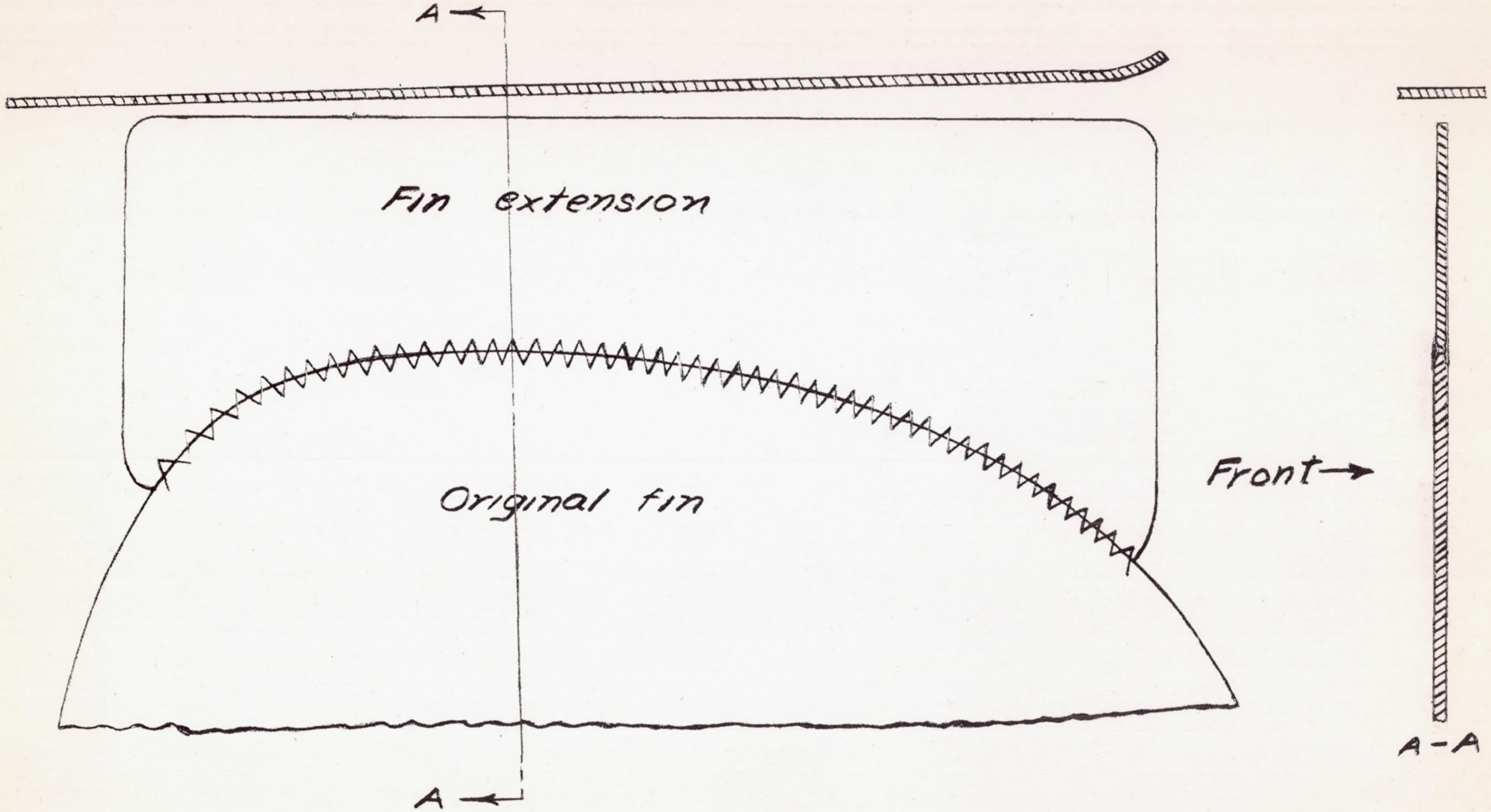


Figure 3.- Typical butt-welded fin extension as installed on top of cylinder head 1.

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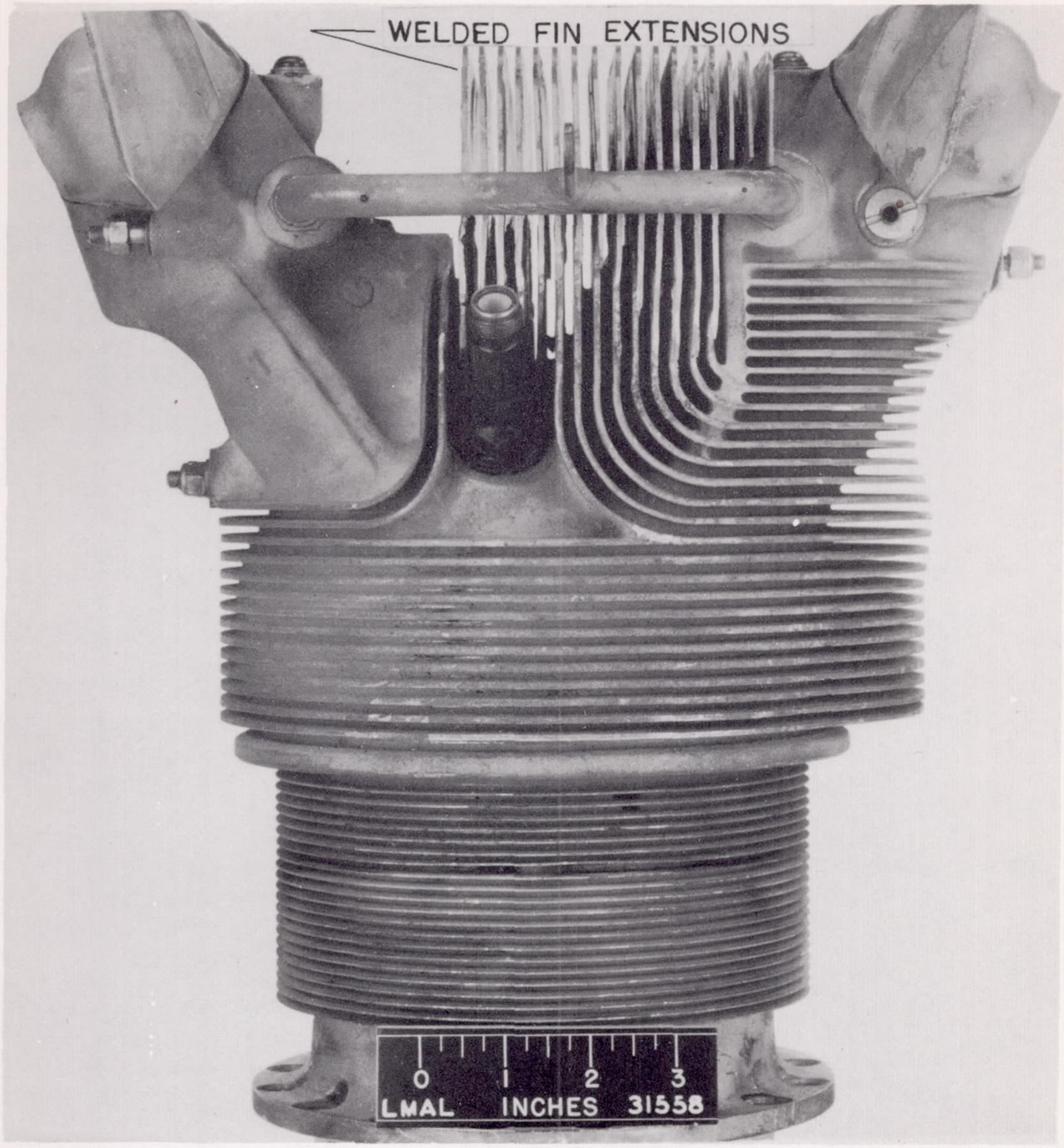

Figure 4.- View of cylinder 1 showing welded fin extensions.

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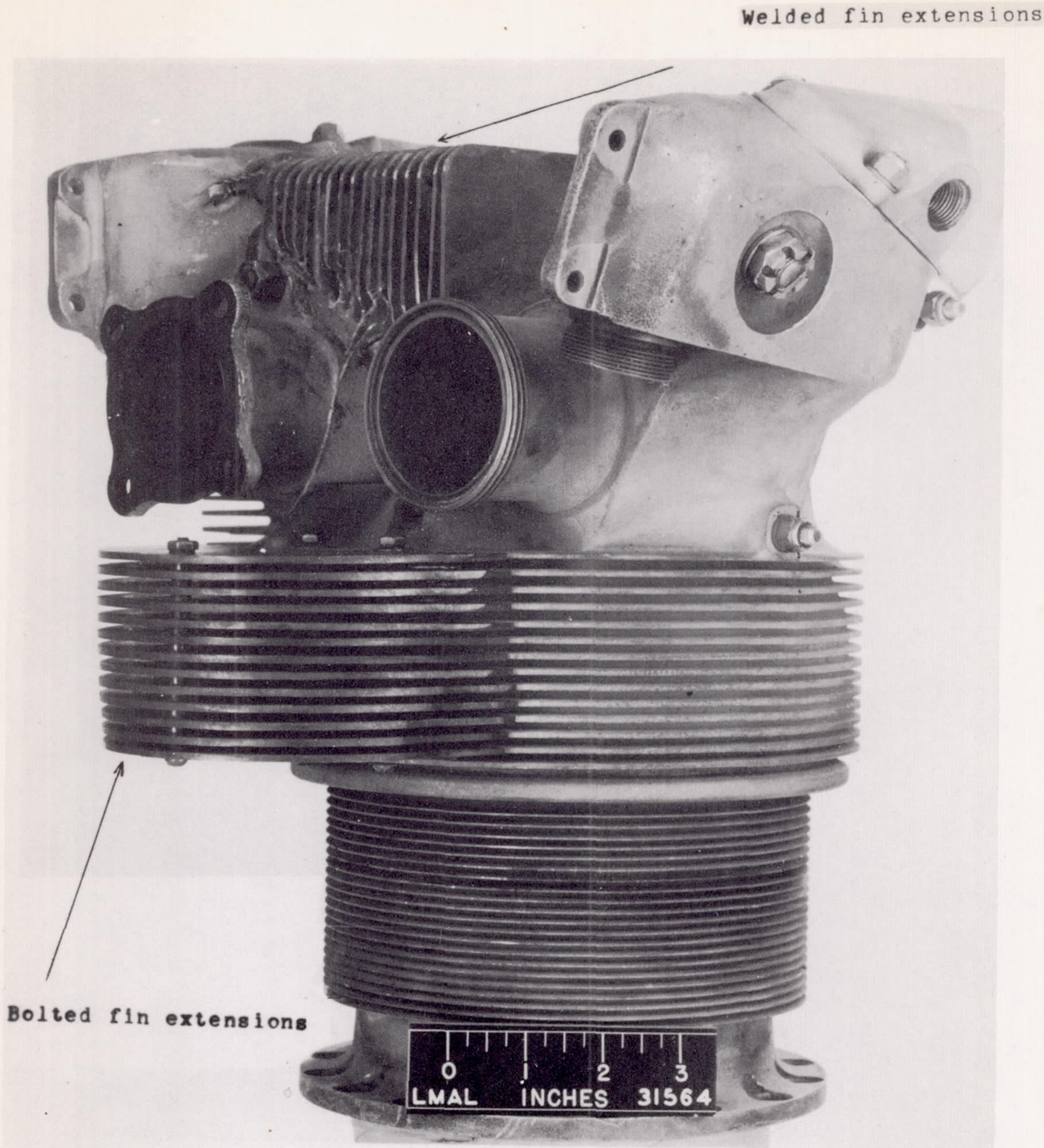

Figure 5.- View of cylinder 1 showing welded and bolted fin extensions.

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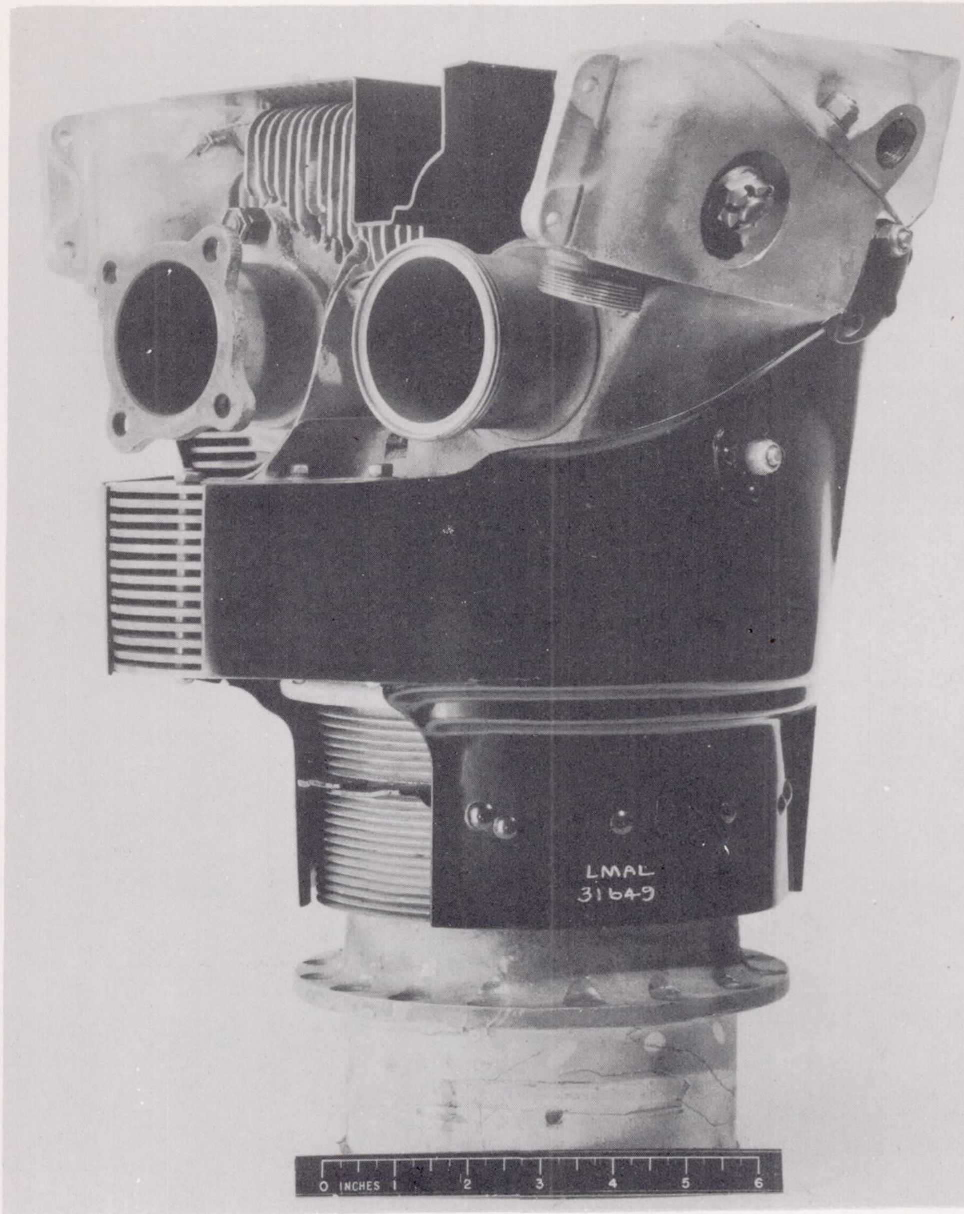


Figure 6.- View of cylinder 1 showing fin extensions and baffles.

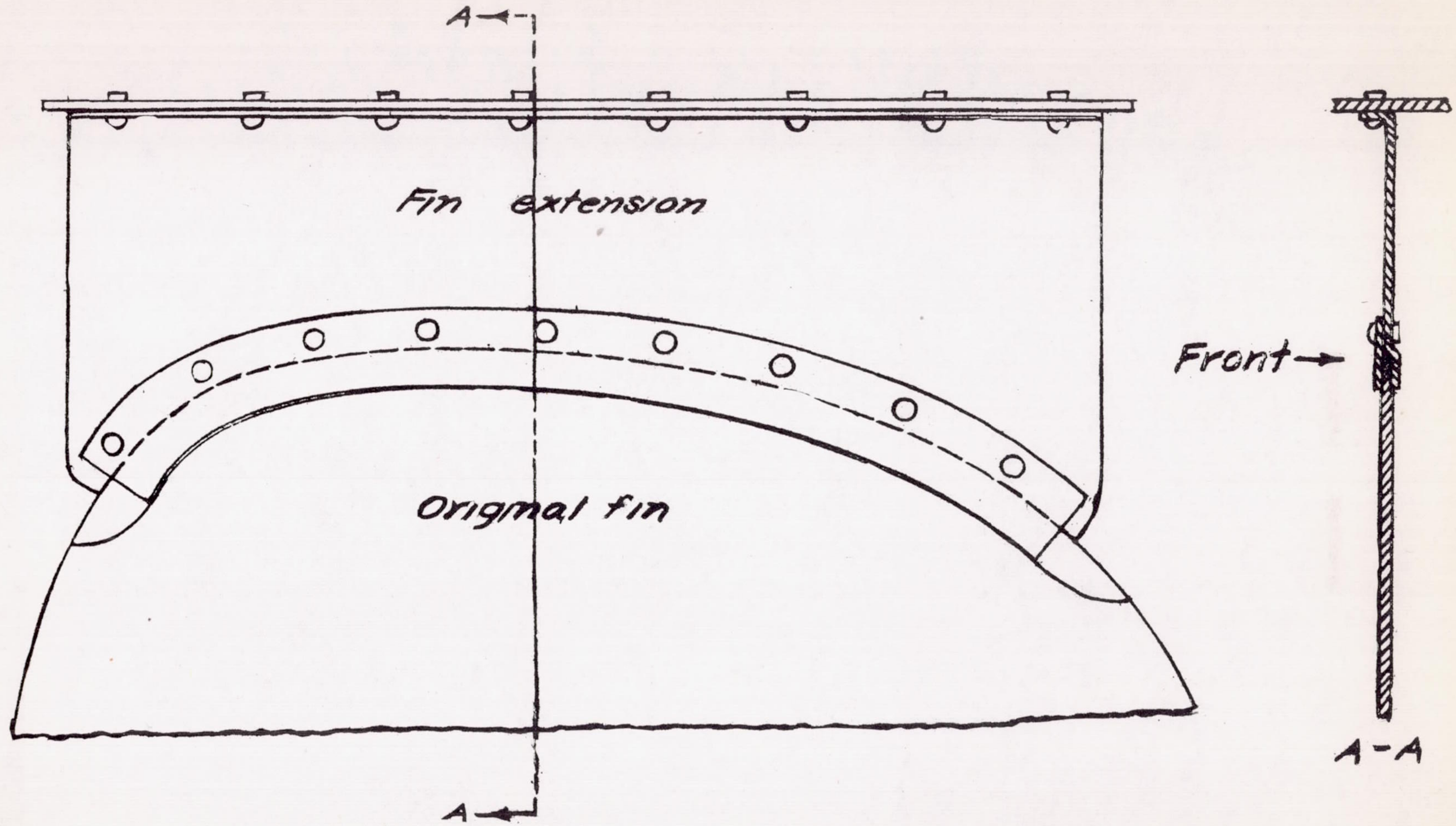


Figure 7. - Typical clipped fin extension as installed on top of cylinder head 13.

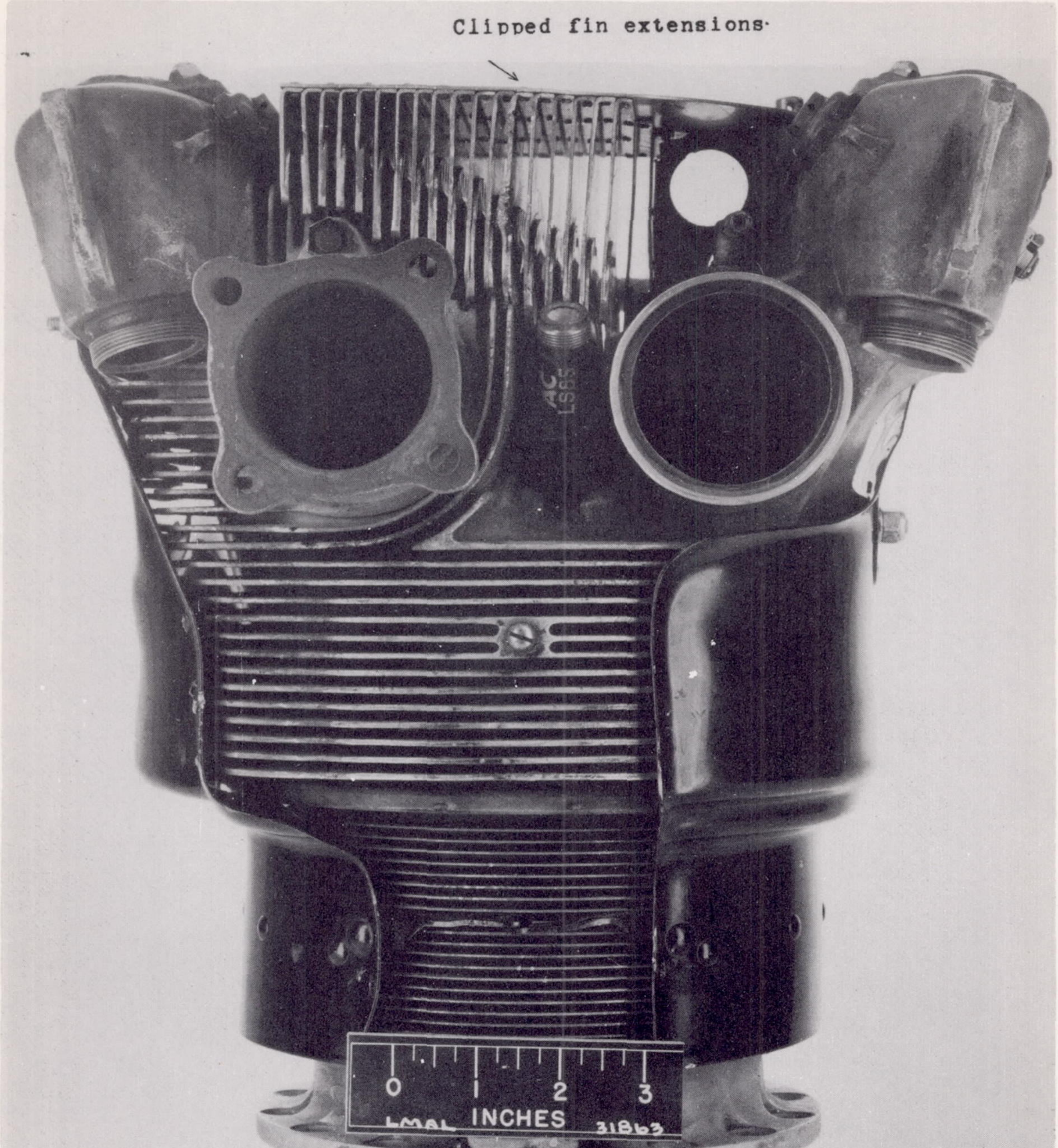


Figure 8.- View of cylinder 13 showing clipped fin extensions.

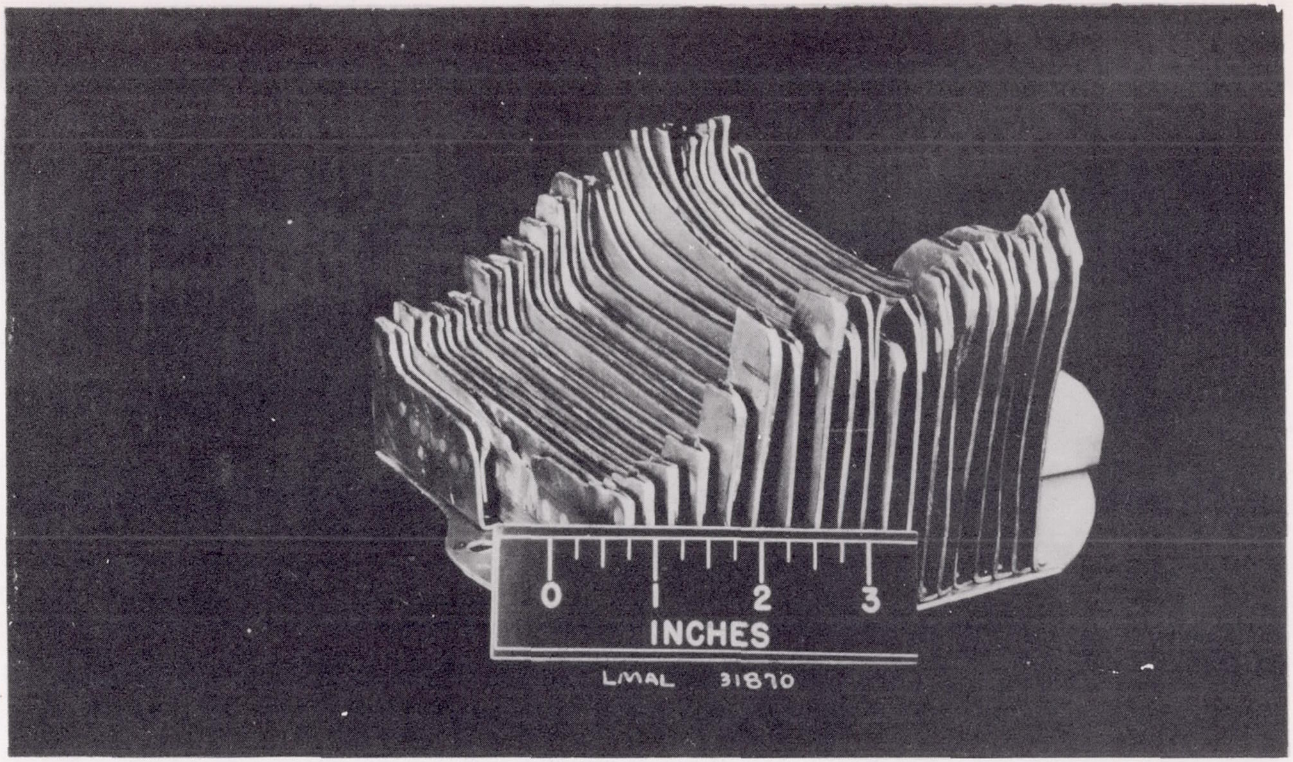
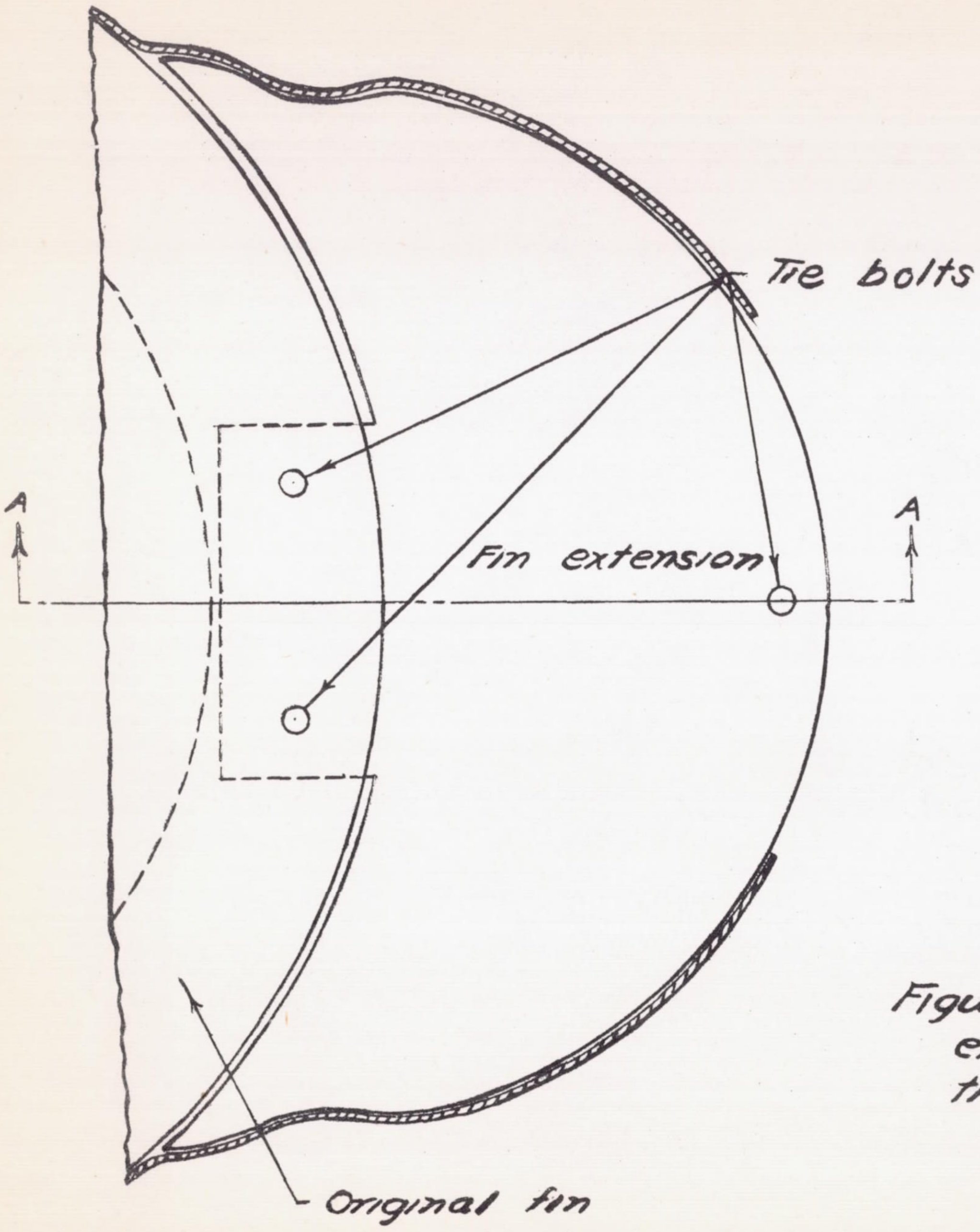


Figure 9.- Clipped fin extensions as installed on cylinder 13.



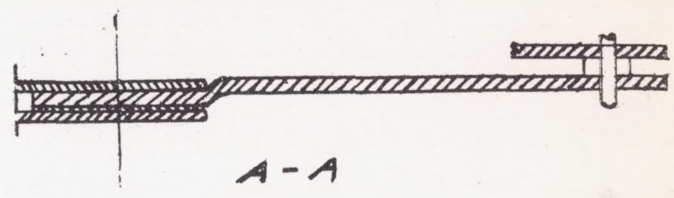


Figure 1a – Typical bolted fin extension as installed on the rear of cylinder head 1.

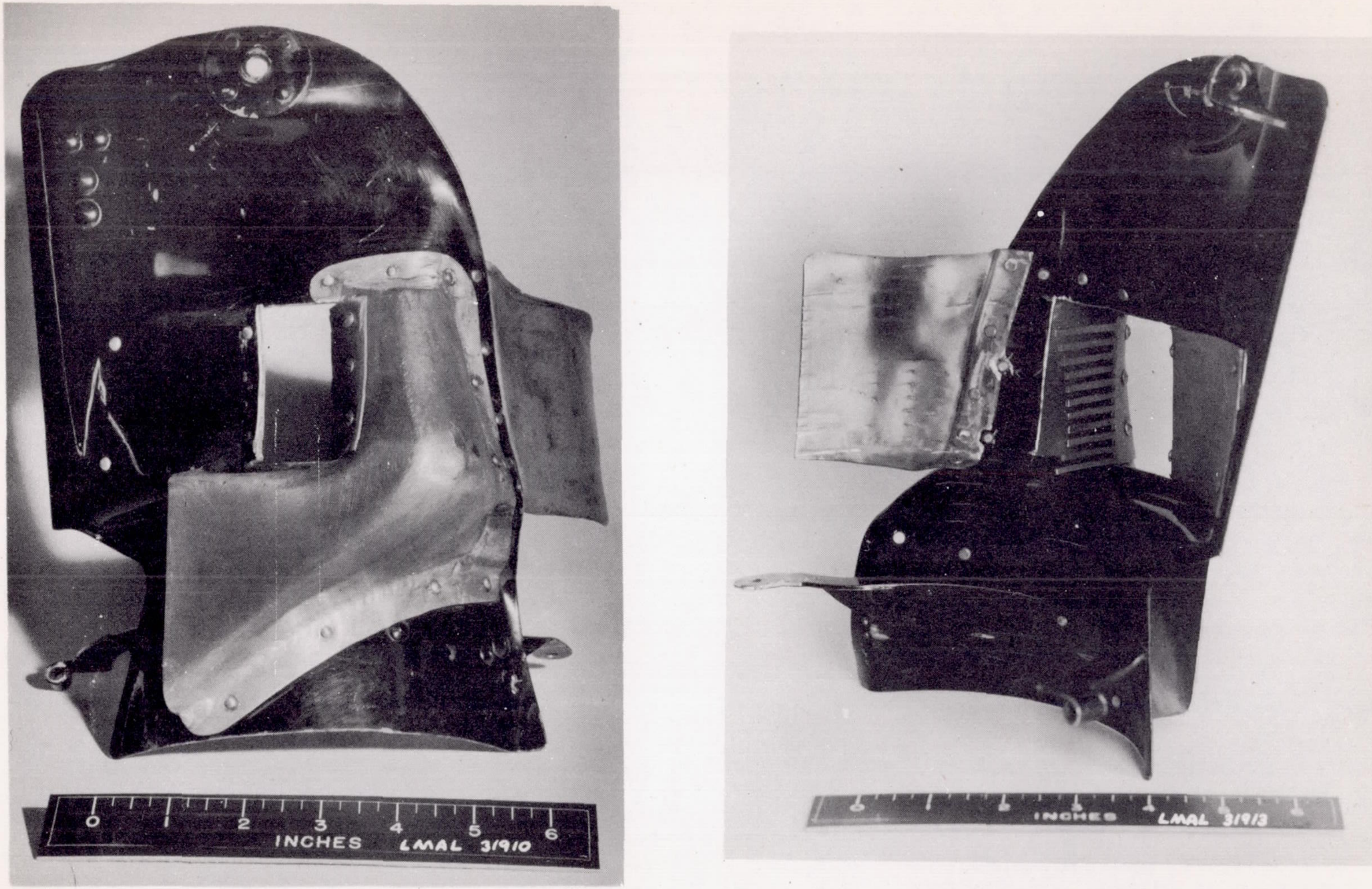


Figure 11.- Views of rear-cylinder side baffle with a separate cooling-air duct.

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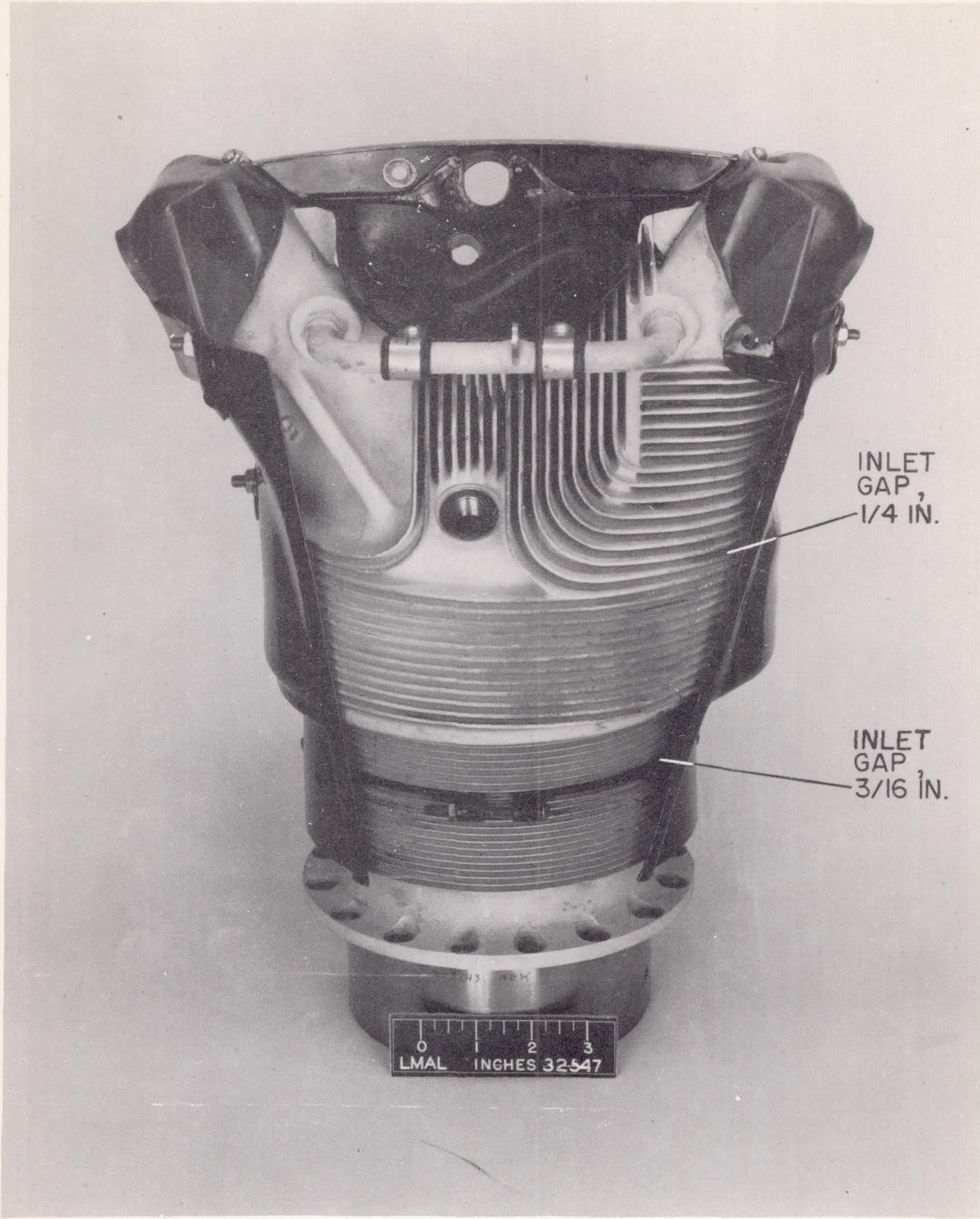

(a) Original baffle.

Figure 12.- Comparison of original and revised baffles. Front view.

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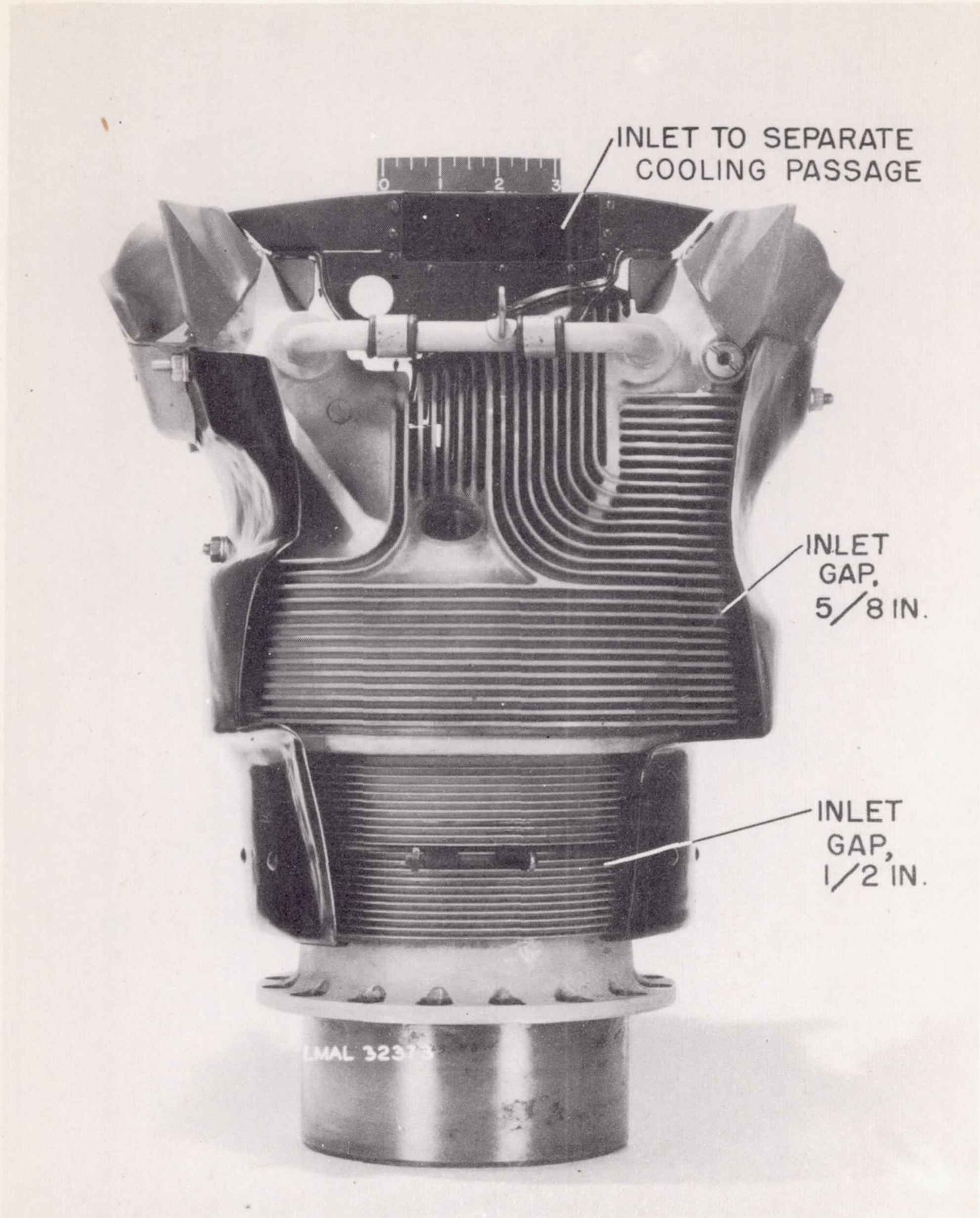
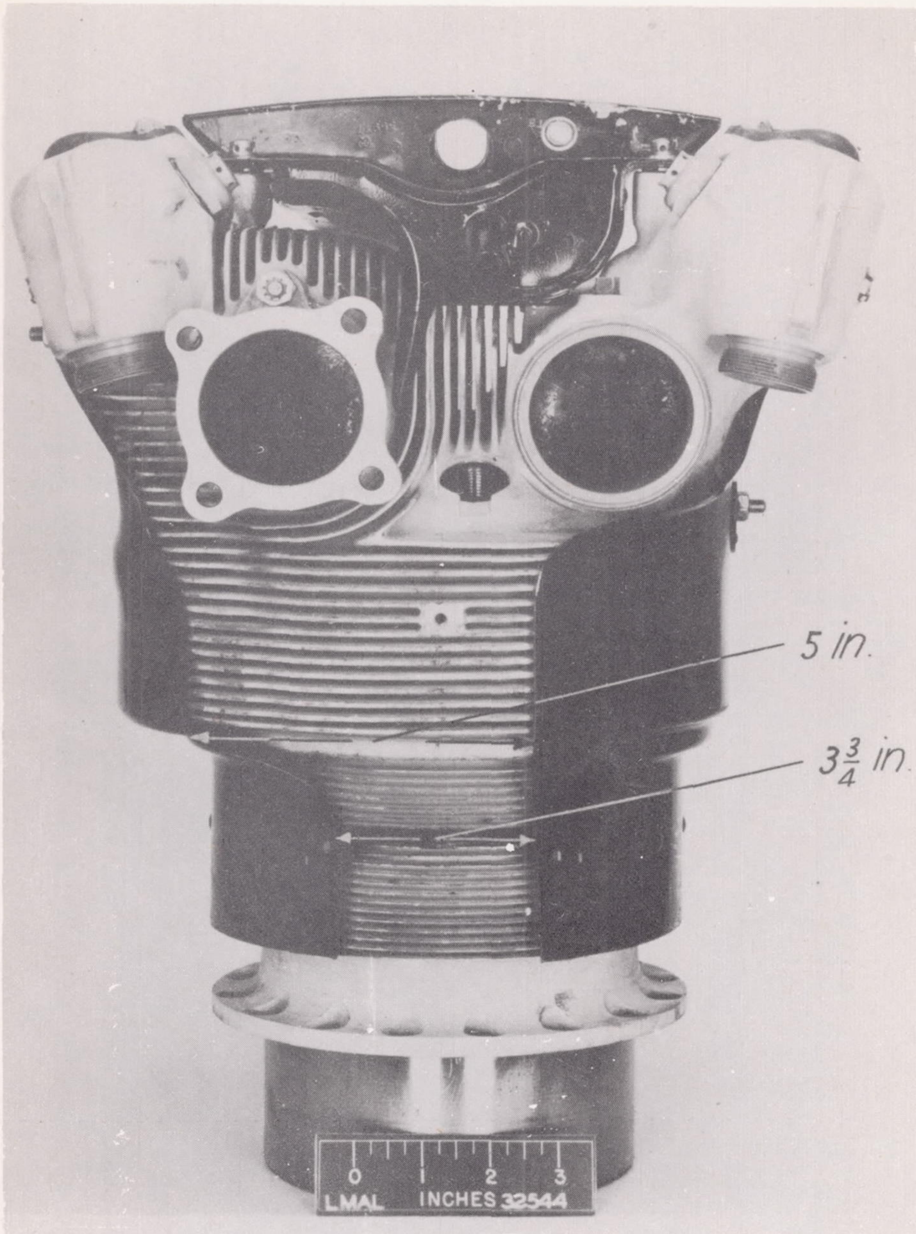


(b) Revised baffle.

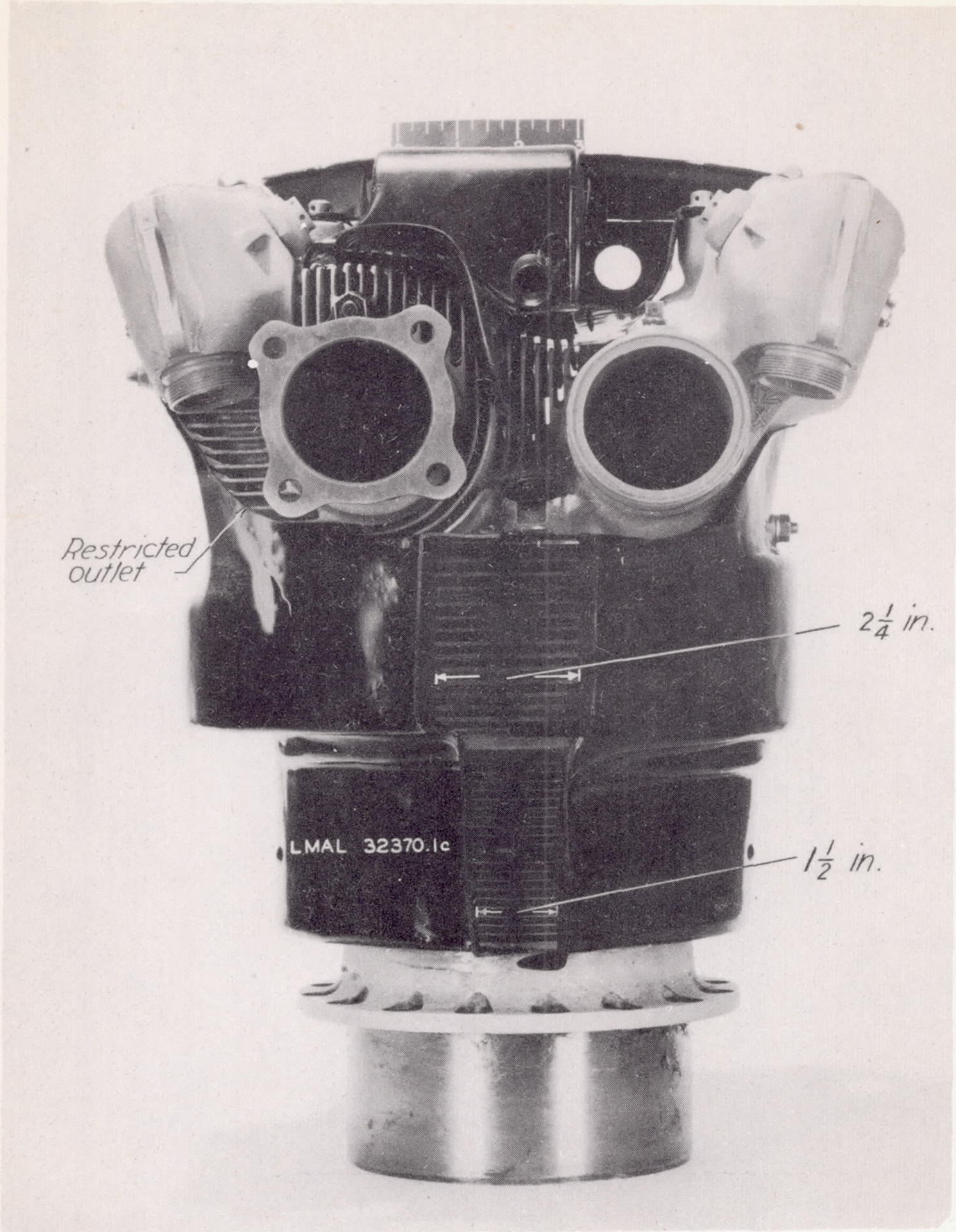
Figure 12.- Concluded.

L-640



(a) Original baffle.

Figure 13.- Comparison of original and revised baffles. Rear view.



(b) Revised baffle.

Figure 13.- Concluded.

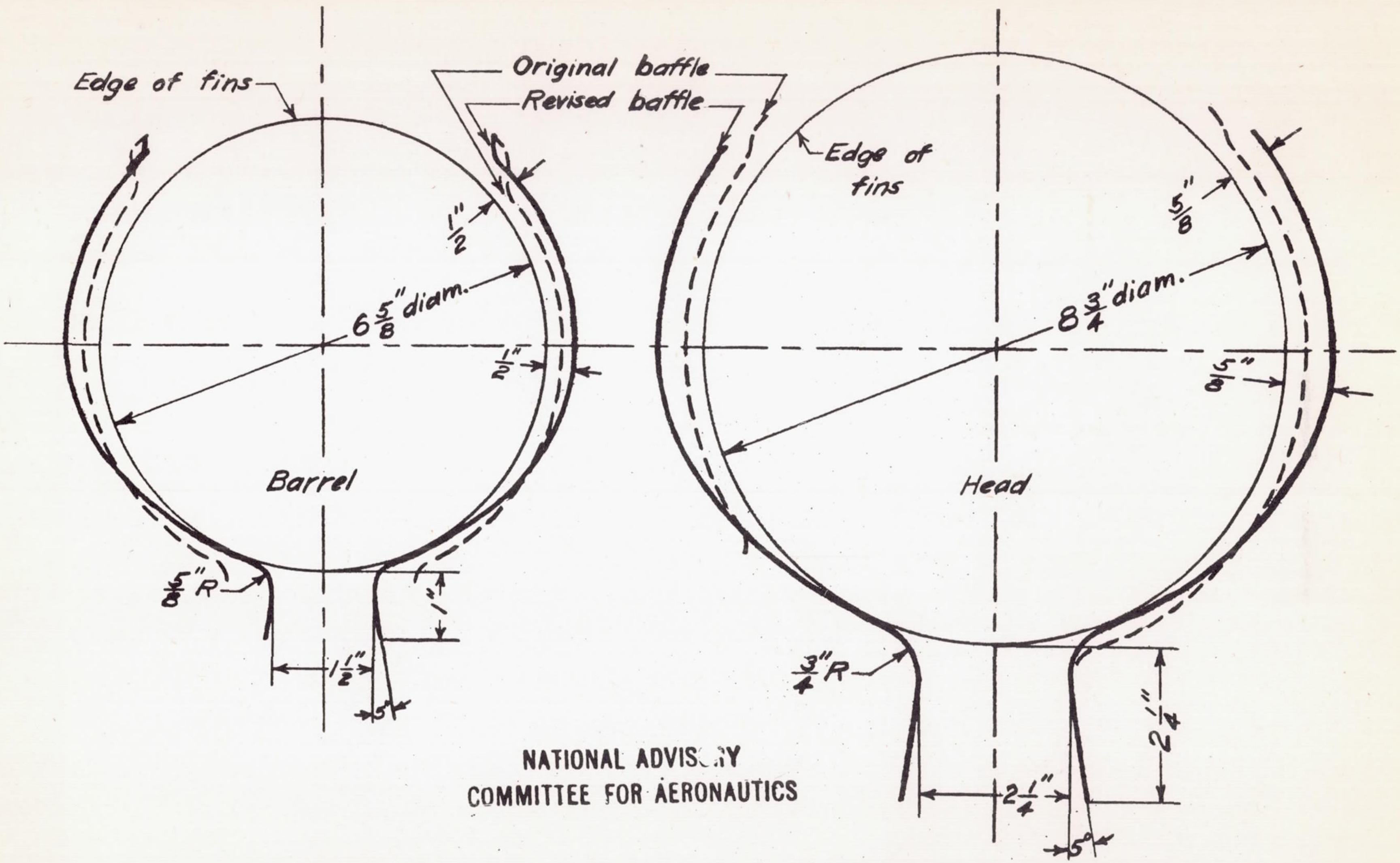
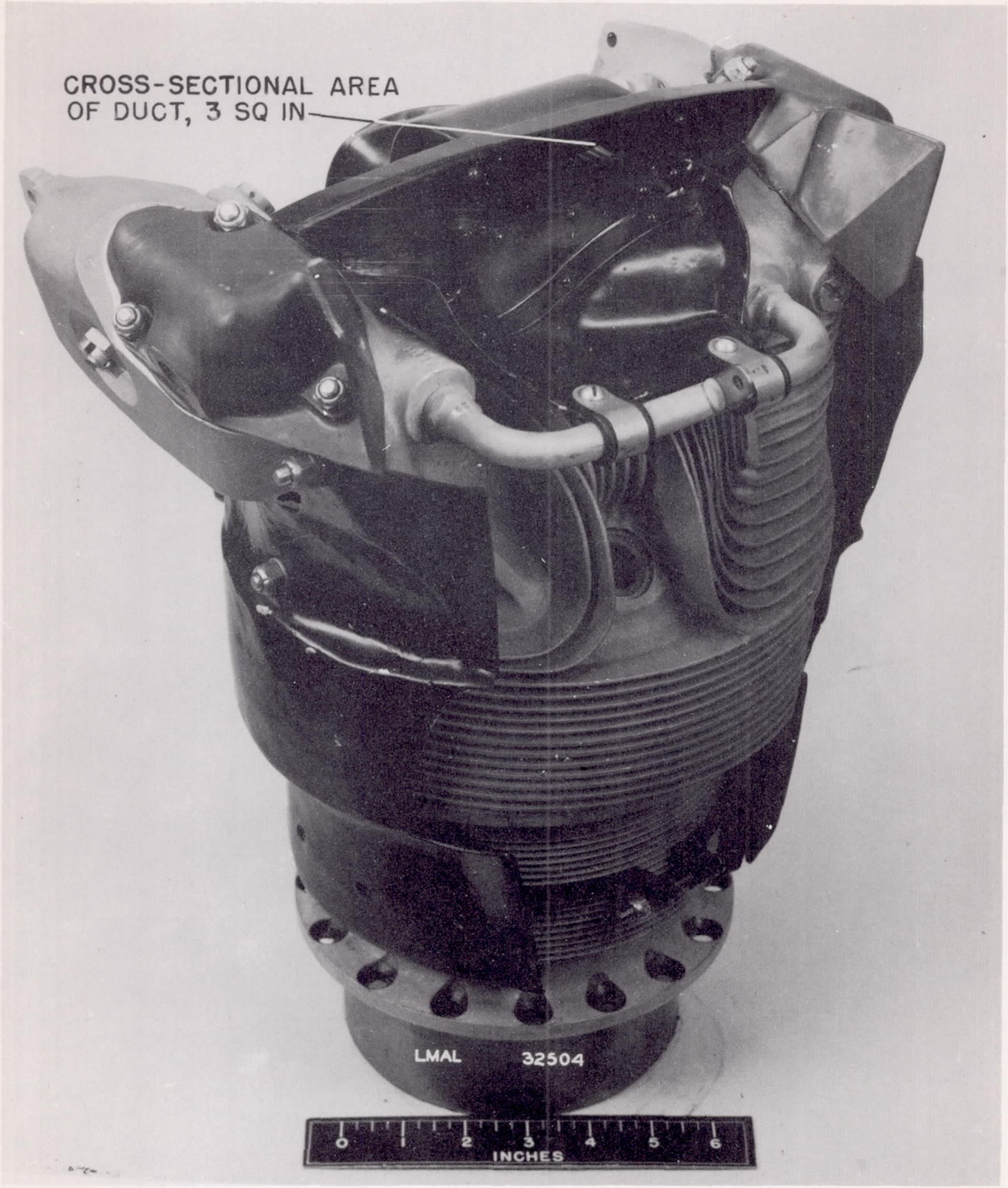


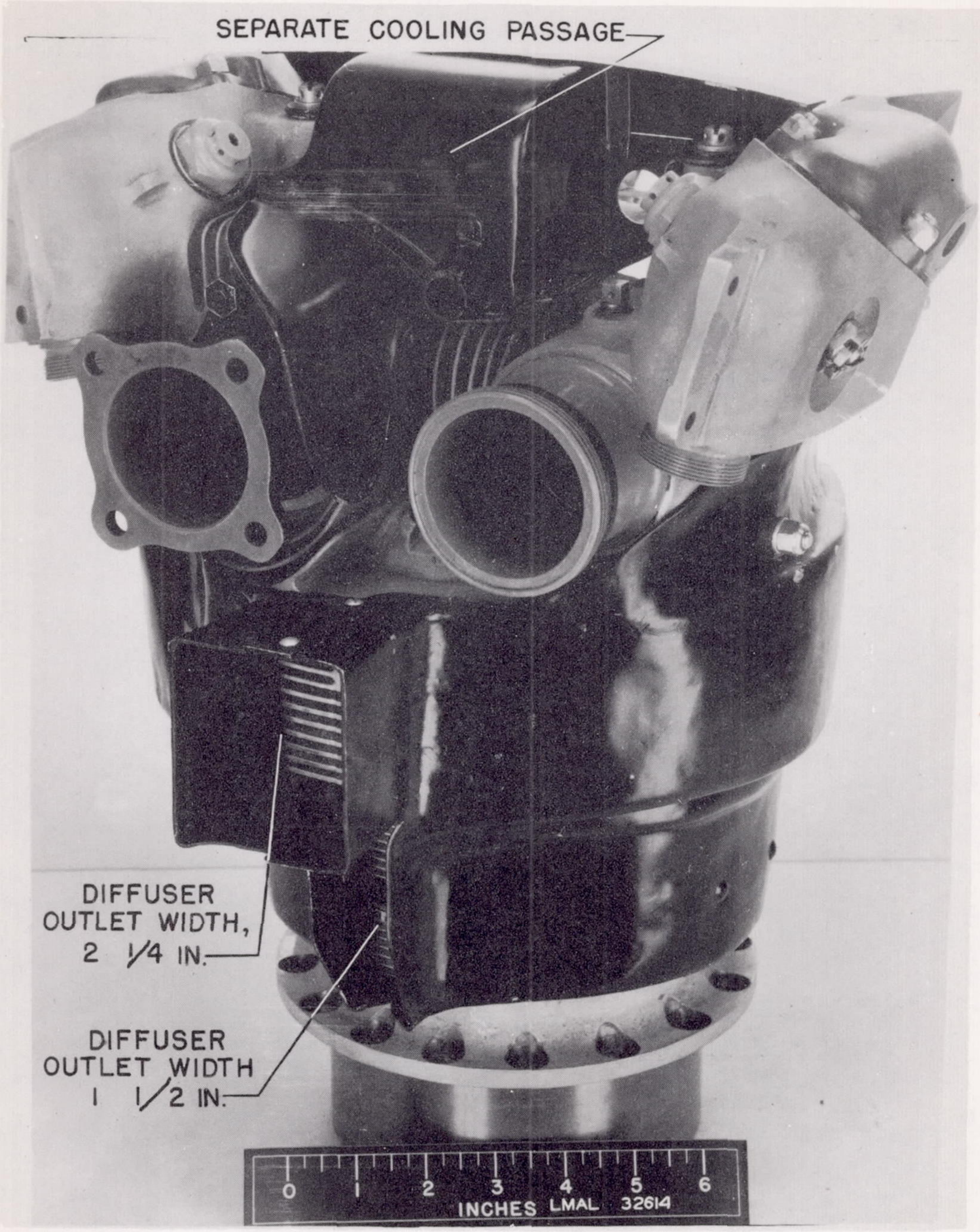
Figure 14.- Sections through cylinder head and barrel showing contour of original and revised baffles tested on rear cylinders.

L-640



(a) Three-quarter front view.

Figure 15.- Revised baffles installed on rear cylinder of P. & W. R-1830-43 engine.



(b) Three-quarter rear view.

Figure 15.- Concluded

L-640

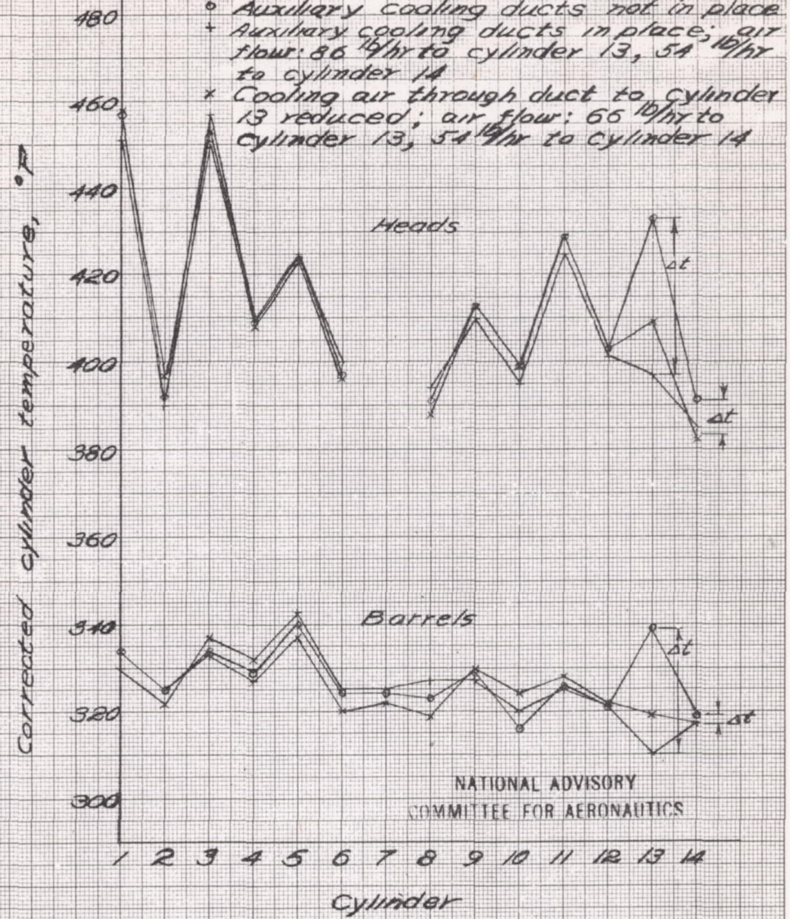


Figure 16.- Effect on cylinder temperatures of auxiliary cooling ducts to cylinders 13 and 14 at 97 percent normal power.

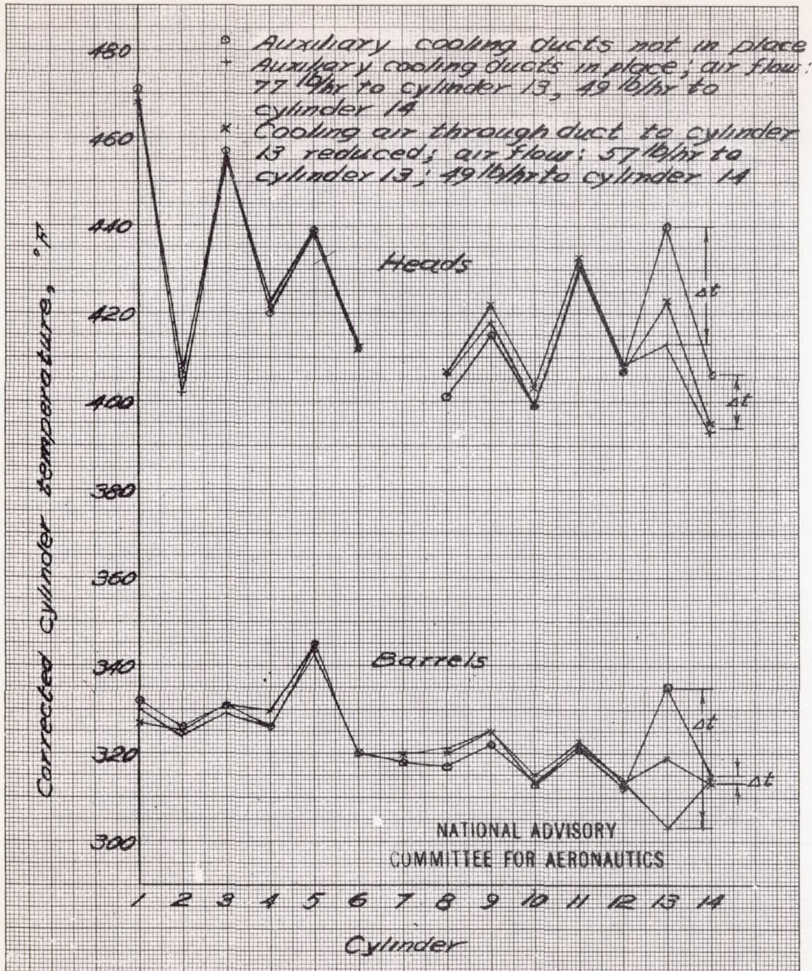


Figure 17.- Effect on cylinder temperatures of auxiliary cooling ducts to cylinders 13 and 14 at 58 percent normal power.

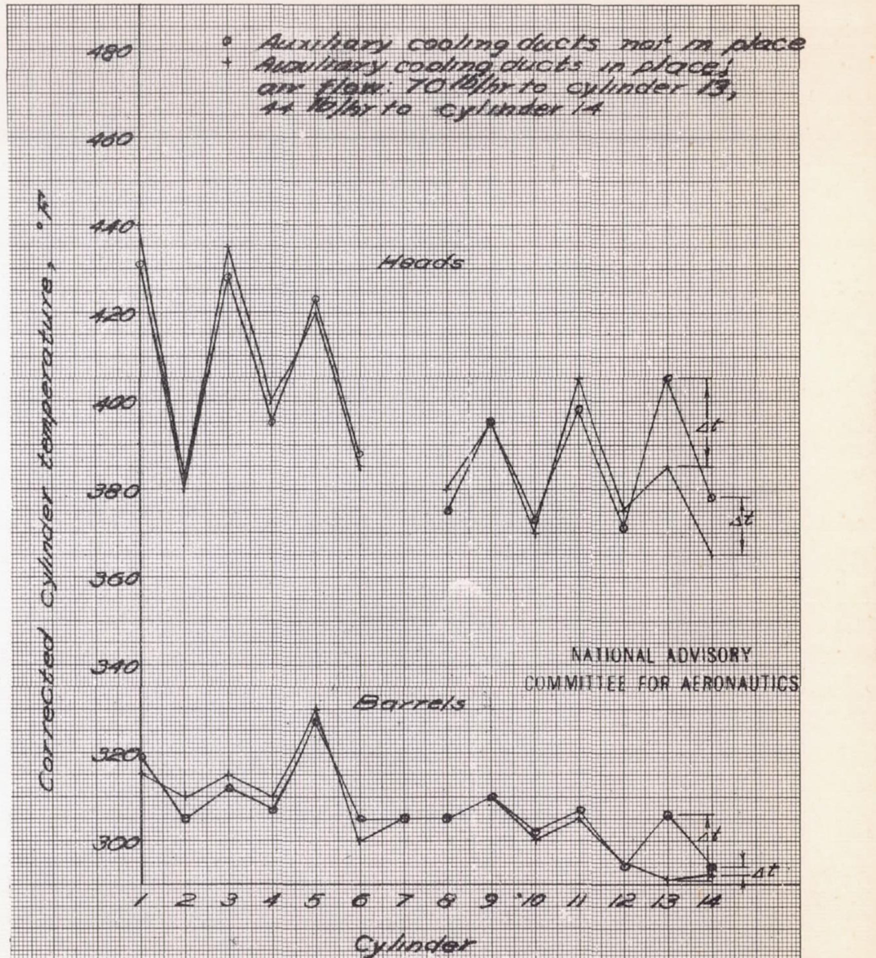


Figure 18.- Effect on cylinder temperatures of auxiliary cooling ducts to cylinders 13 and 14 at 48 percent normal power.

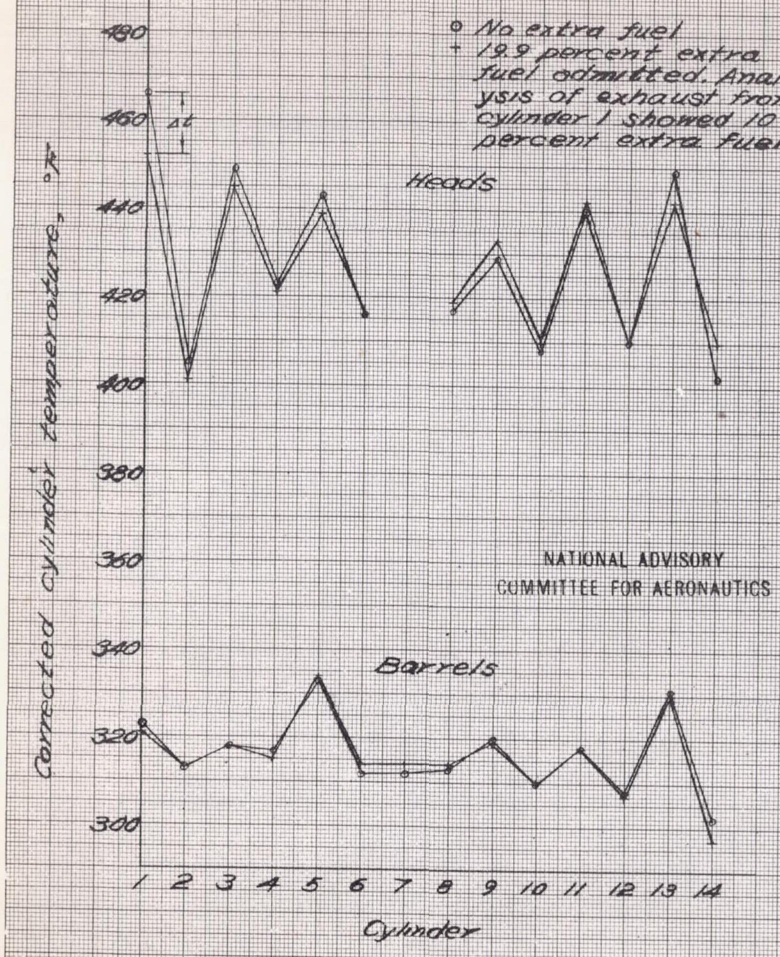


Figure 19.- Effect on cylinder temperatures of direct fuel injection into cylinder 1 at 59 percent normal power. Average engine fuel-air ratio, 0.068.

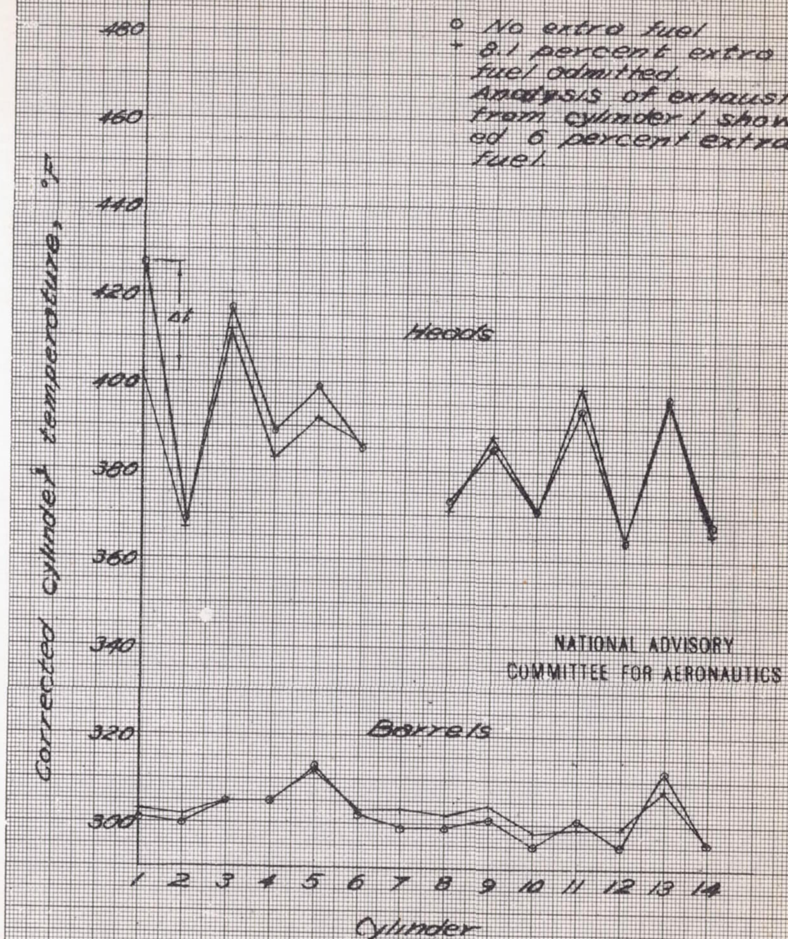


Figure 20.- Effect on cylinder temperatures of direct fuel injection into cylinder 1 at 97 percent normal power. Average engine fuel-air ratio, 0.110.

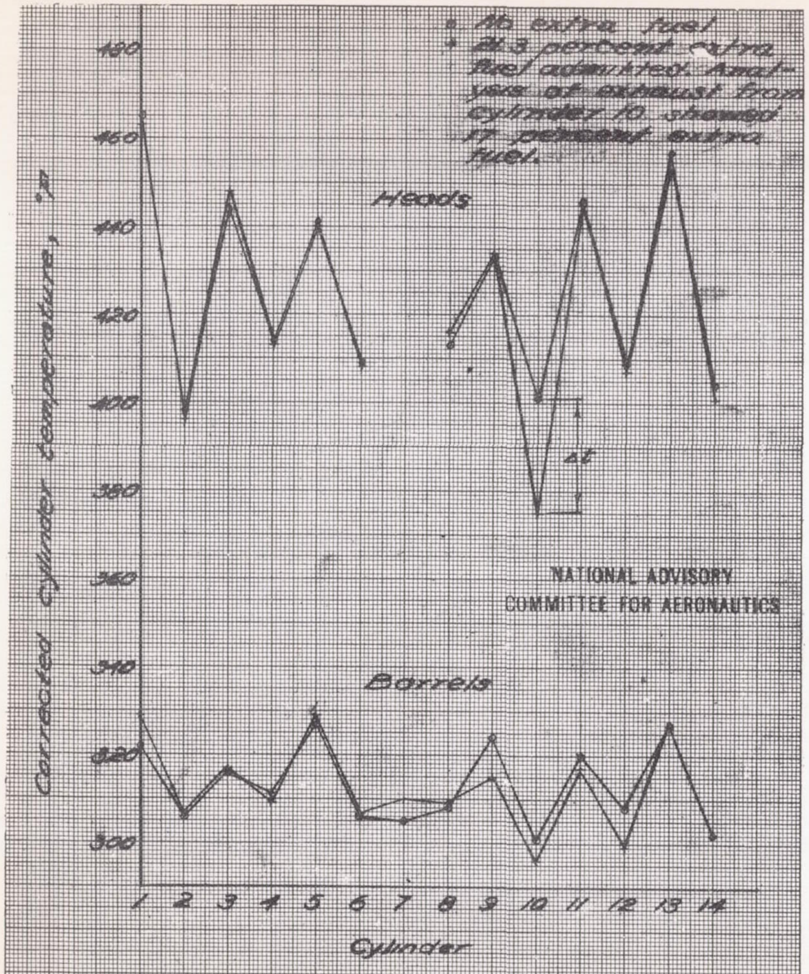


Figure 21.- Effect on cylinder temperatures of direct fuel injection into cylinder 10 at 57 percent normal power. Average engine fuel-air ratio, 0.070.

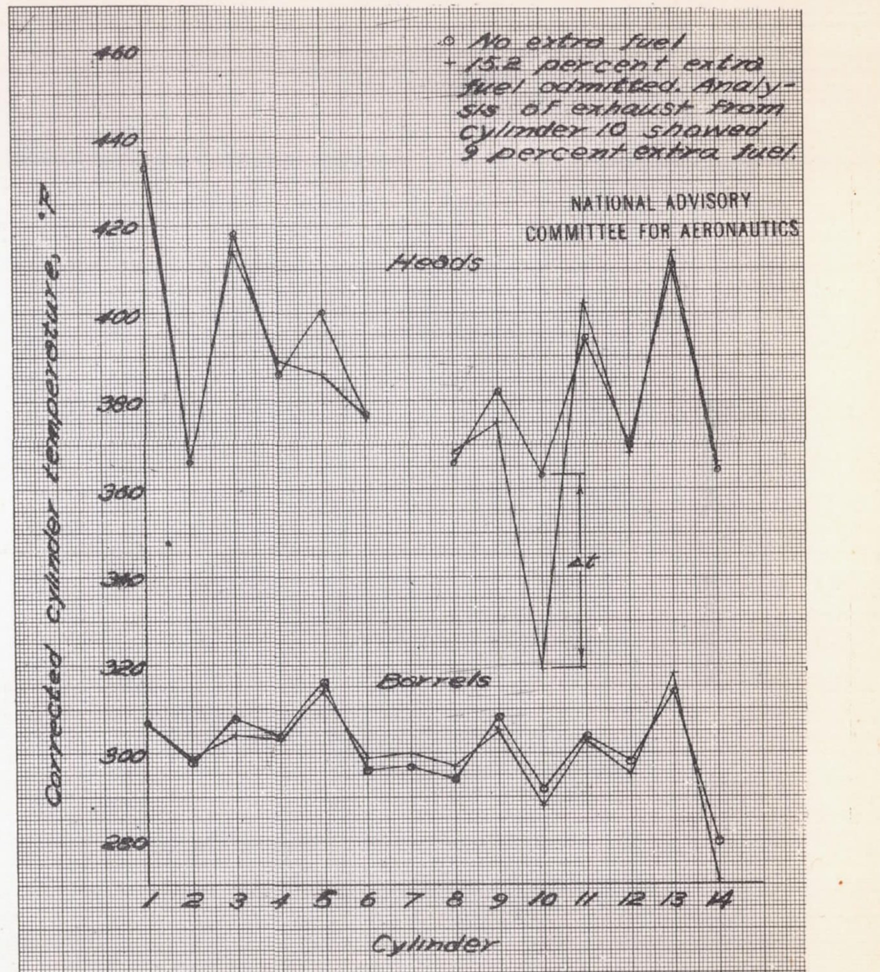
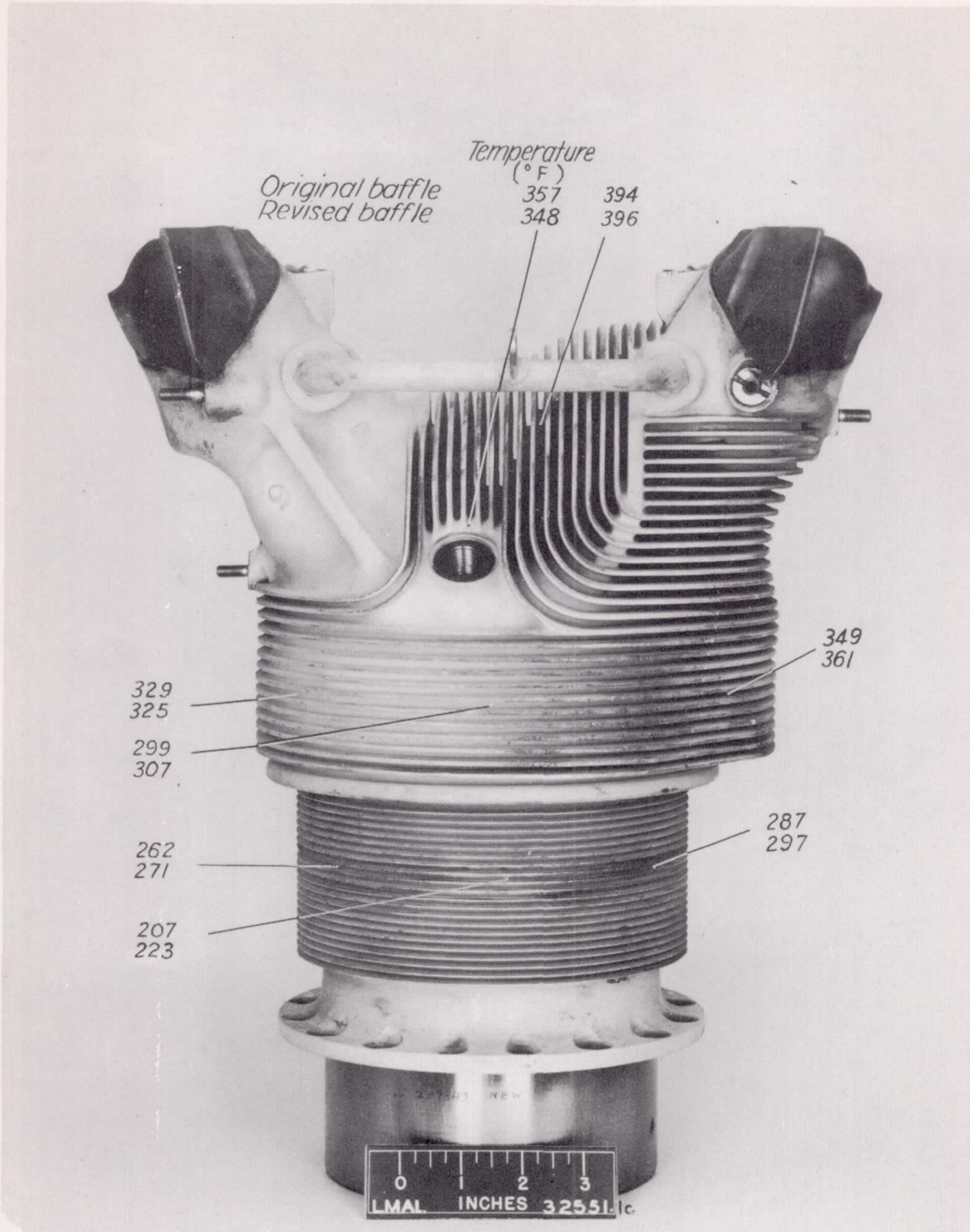


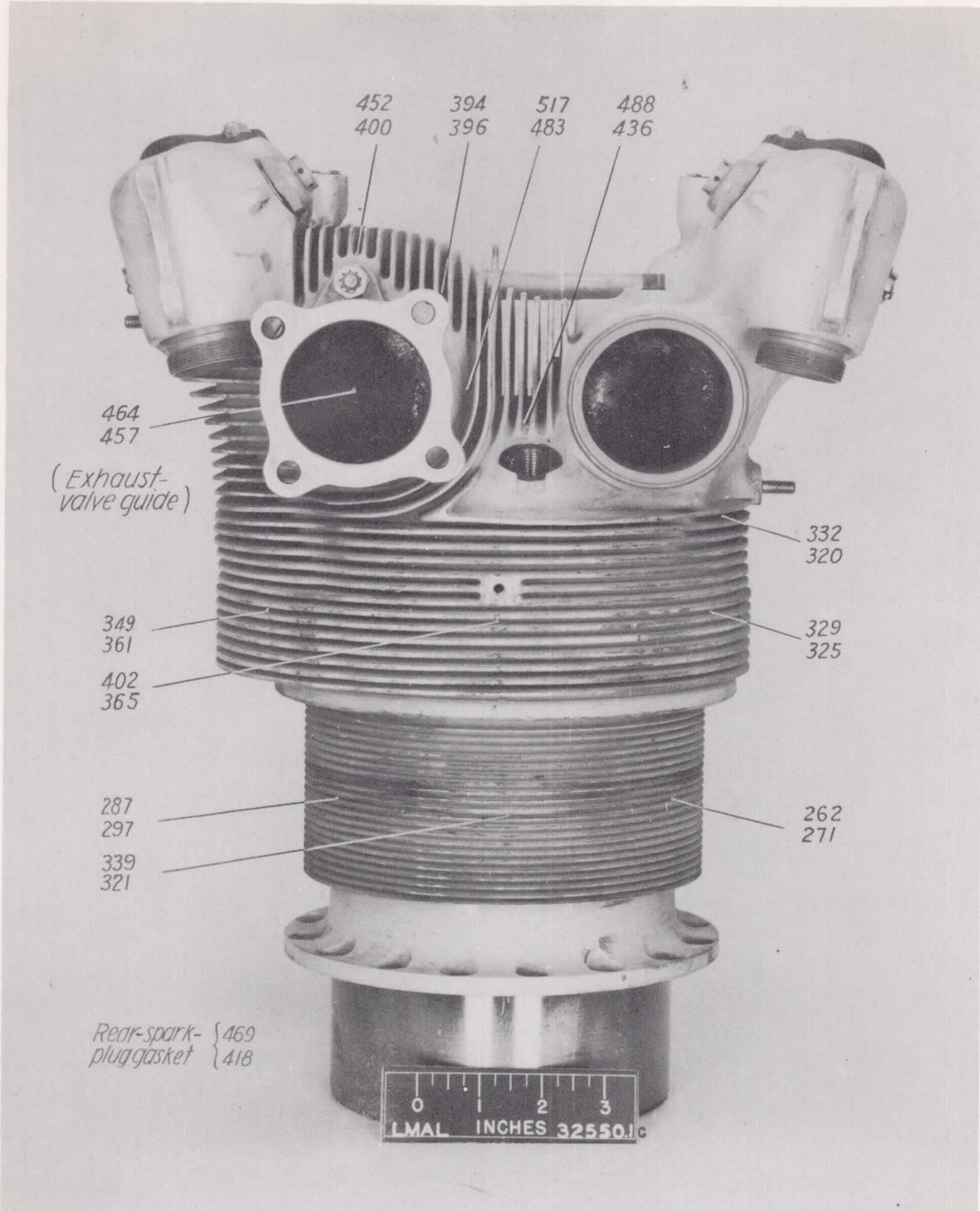
Figure 22.- Effect on cylinder temperatures of direct fuel injection into cylinder 10 at 97 percent normal power. Average engine fuel-air ratio, 0.110.

L-640



(a) Front view.

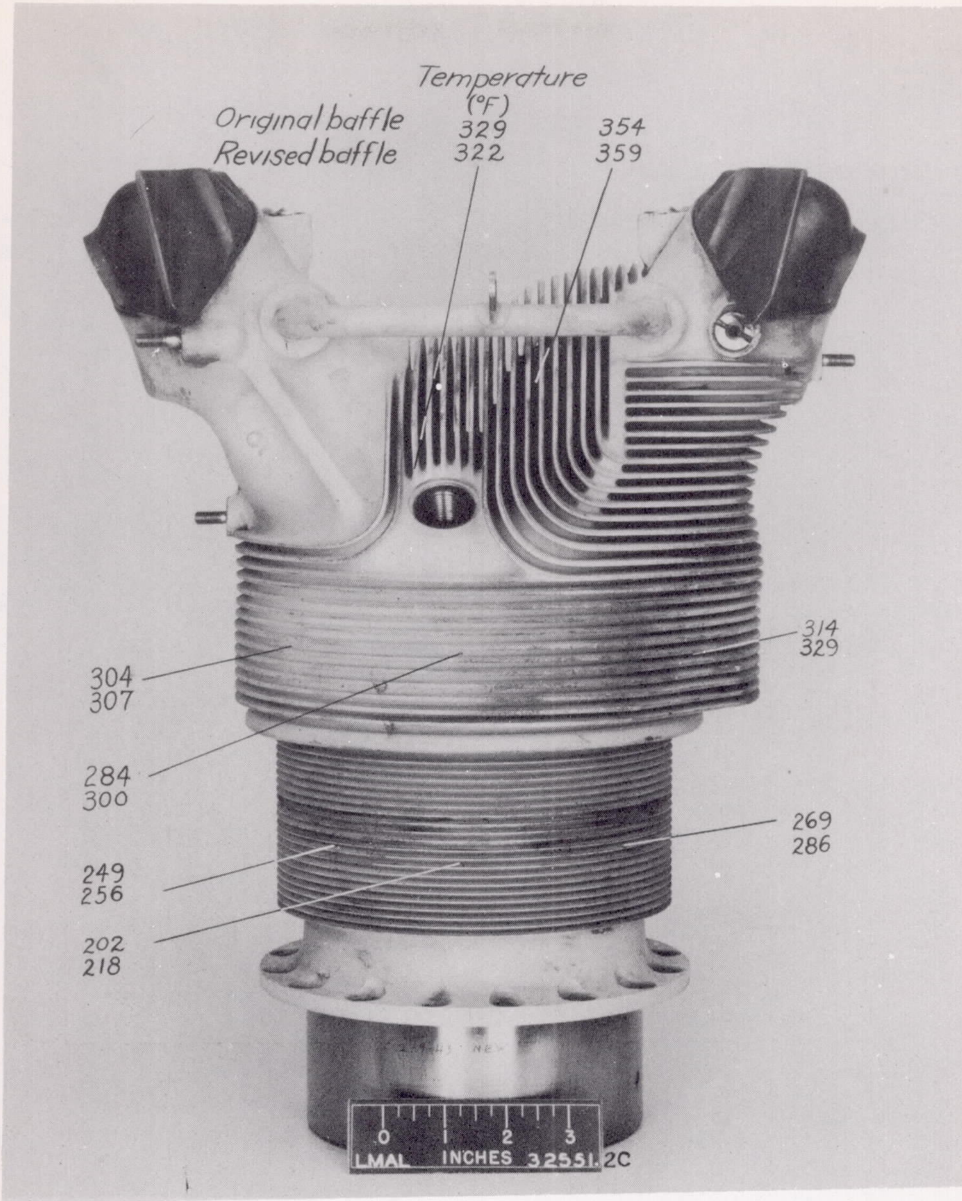
Figure 23.- Temperature on cylinder 1 with original and revised baffles. Engine speed, 2250 rpm; manifold pressure, 28.0 inches of mercury; engine fuel-air ratio, 0.072; average cooling pressure drop $\sigma \Delta p$, 3.41 inches of water.



(b) Rear view.

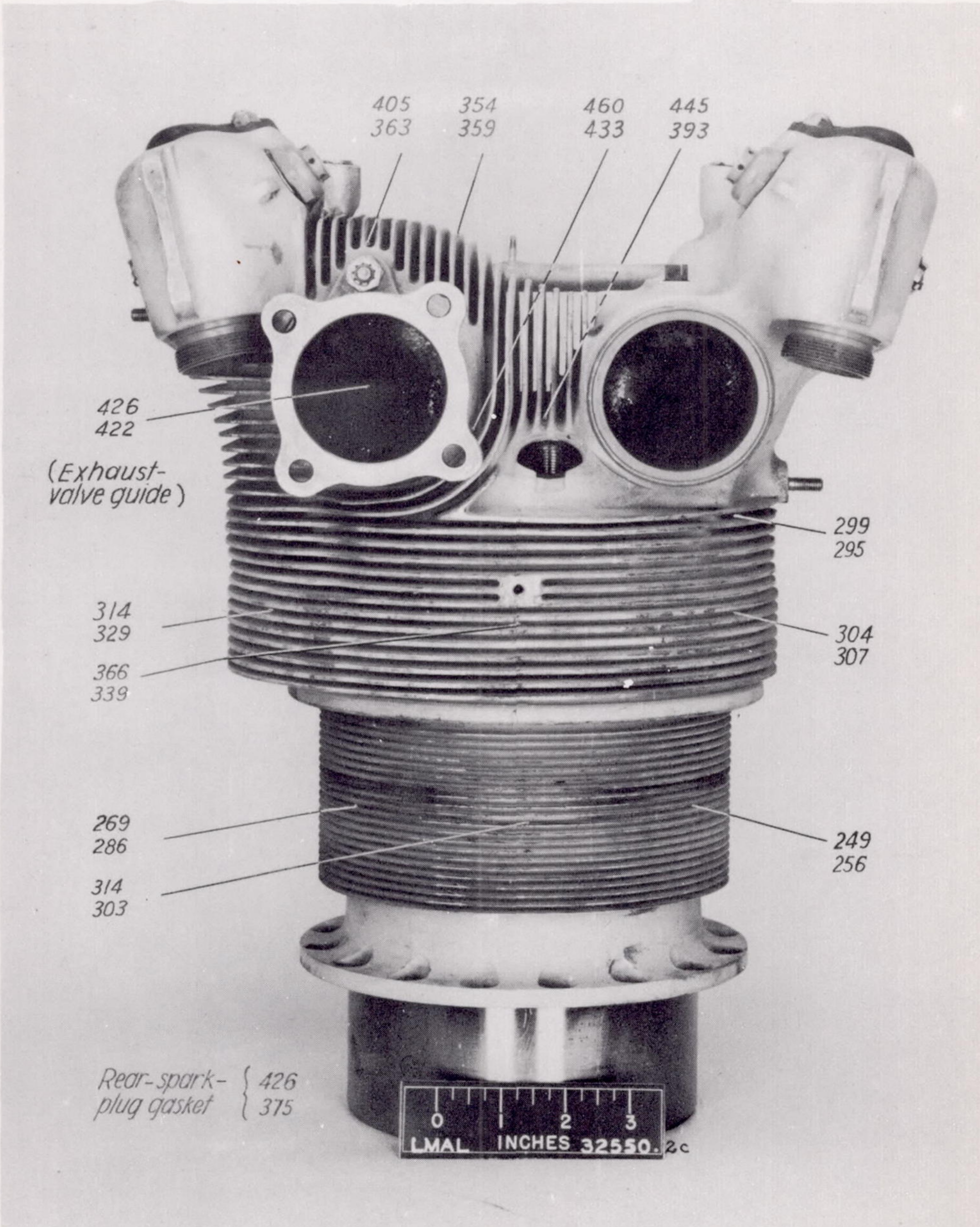
Figure 23.- Concluded.

L-640



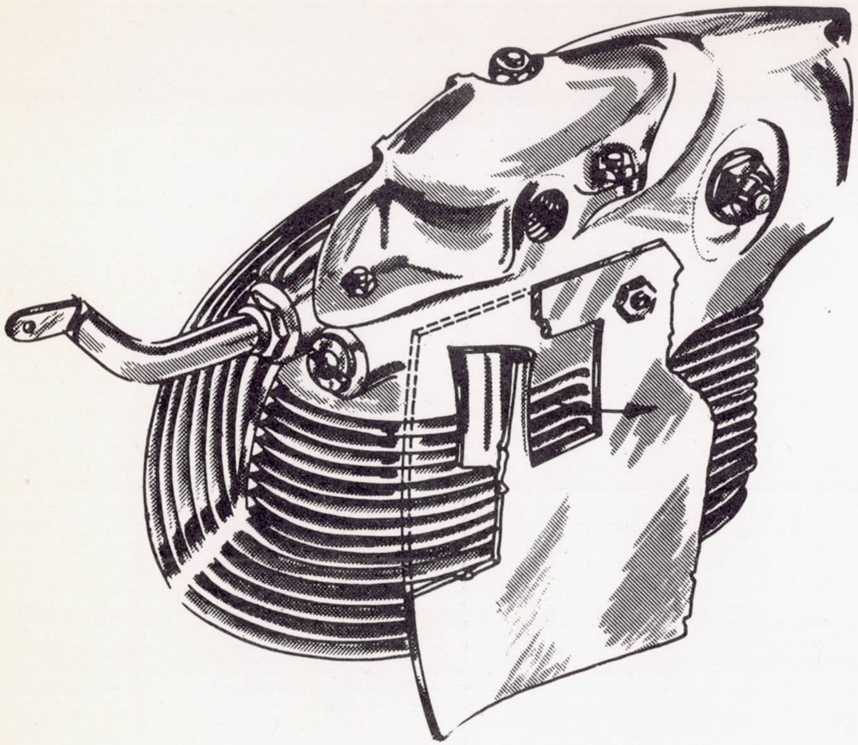
(a) Front view.

Figure 24.- Temperature on cylinder 1 with original and revised baffles. Engine speed, 2550 rpm; manifold pressure, 39.5 inches of mercury; engine fuel-air ratio, 0.105; average cooling pressure drop $\sigma\Delta p$, 4.51 inches of water.

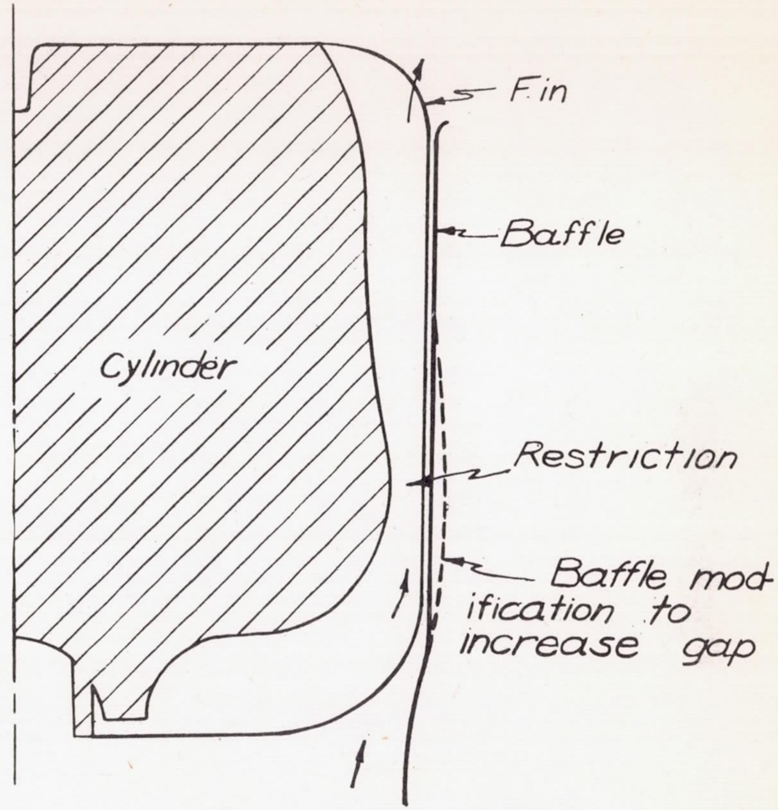


(b) Rear view.

Figure 24.- Concluded.



(a) Small outlet cut in revised baffles to allow cooling air to pass between the topmost fins on front of rocker box.



(b) Modification of revised baffles to increase cooling-air flow around side of rocker box by increasing gap between the fins and baffle where fins are short.

Figure 25.- Modifications to revised baffles to reduce the temperature of the exhaust-valve guide.