NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1053

USE OF DUCTED HEAD BAFFLES TO REDUCE REAR-ROW CYLINDER TEMPERATURES OF AN AIR-COOLED AIRCRAFT ENGINE

By Michael A. Sipko, Charles B. Cotton, and James B. Lusk

Aircraft Engine Research Laboratory
Cleveland, Ohio

Washington
August 1946

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 1053

USE OF DUCTED HEAD BAFFLES TO REDUCE REAR-ROW CYLINDER TEMPERATURES OF AN AIR-COOLED AIRCRAFT ENGINE

By Michael A. Sipko, Charles B. Cotton, and James B. Lusk

SUMMARY

The effectiveness of ducted head baffles in reducing temperatures of rear-row exhaust-valve seats was determined from tests with a two-row radial engine. Two types of ducted head baffle were investigated on an engine-propeller test stand; the better of the two was investigated in flight. A reduction of approximately 50° F in the average temperature of the rear-row exhaust-valve seat was obtained in flight and the reductions were reasonably consistent for all cylinders, ranging between 35° F and 80° F. During level flight, the maximum temperature of the exhaust-valve seat obtained when using ducted baffles on all rear-row cylinders was reduced 50° F to 70° F below the maximum temperature of the exhaust-valve seat obtained when using conventional baffles on all rear-row cylinders.

INTRODUCTION

Continual efforts toward the improvement of the cooling performance of air-cooled engine installations has demonstrated the problem of cylinder-baffle design to be primarily one of directing to each portion of the cylinder area the least amount of air that will cool the engine properly. The success of engine cowlings in reducing the aerodynamic resistance of aircraft-engine installations by limiting the air flow over the engine (references 1 and 2) first emphasized the necessity for careful utilization and direction of cooling air. The simple deflector (references 1 and 3), developed to direct the air flow to the more critical areas of the cylinders, demonstrated that by guiding the air flow across the engine cylinders the required cooling-air flow could be further reduced. From an investigation of cylinder baffles (reference 4), it developed that the most efficient utilization of cooling air occurred when the baffles were situated very close to the fin tips. Exceptions to this rule were necessary where the fin was of nonuniform width (reference 5) and such cases necessitated lifting the baffles from the fin tips in order to provide an effectively uniform airflow passage. Although this arrangement appeared optimum for cylinders with relatively uniform heat dissipation, further baffle modifications become necessary where critical cylinder areas overheat. Distribution of cooling air to remove temperature nonuniformities is facilitated by addition of special ducts designed to carry the air to overheated regions of the cylinder. Baffles incorporating this principle appeared first on the BMW-801 engine and subsequently found further application (references 6 and 7) in slightly modified forms.

Each application of ducted head baffles is a special problem depending on the nature of the cooling factors. Of particular interest is the problem of cooling a critical region, interior to the cylinder, by augmentation of external surface cooling. In the present investigation, it was desired to cool the exhaust-valve seats on the rear-row cylinders of a two-row radial engine. The exhaust-valve seats of the rear-row cylinders had been observed to operate approximately 80° F hotter than those of the front row. Because fins below the exhaust port were in a region of relatively stagnant air, it appeared that ducts might be used to direct cooling air to the external valve-seat region and thereby reduce the internal temperature. Two ducted head baffles were designed with different duct size and given preliminary tests on the full-scale engine-propeller test stand. Flight tests were then undertaken with the better of the two baffle types. The investigation was conducted at the Cleveland laboratory of the NACA.

DESCRIPTION OF DUCTED BAFFLES

Ducted baffles were designed to conduct cooling air to the high-temperature regions around the exhaust-valve seats of the rear-row cylinders. Because it was desired to augment the cooling-air flow the least amount that would provide adequate cooling, two ducts with different cross-sectional areas were designed to aid in approaching the optimum. The ducts with the small and the large cross-sectional areas will be denoted baffle A and baffle B, respectively.

Baffle A, together with the conventional baffle assembly for the rear-row cylinder, is shown in figure 1. In this design a U-shaped channel was inserted into the conventional cowl-ring baffle to increase the area between the cowl-ring baffle and the inner baffle. The side deflectors on the inner baffle (through which the spark-plug lead passes) were trimmed to accommodate a U-shaped duct that fitted close to the inner baffle and was attached to the modified cowl-ring baffle. This duct was extended over the spark plug and shaped to direct cold air across the horizontal head fins below the exhaust port. The lower end of the duct was supported by a 3/16-inch stud screwed into the boss at the rear of the cylinder. Baffle A increased the weight of the cylinder-baffle assembly 0.58 pound.

Baffle B (fig. 2) utilized a U-shaped channel, slightly larger than that provided in baffle A, inserted in the conventional cowl-ring baffle. The side deflectors on the inner baffle were also trimmed and a formed duct of 3-inch diameter was attached to the modified cowl-ring baffle. The duct extended downward to a flared section and directed most of the cold air against the rear horizontal head fins on the exhaust side. The baffle exit was approximately $3\frac{1}{4}$ inches wide and 3 inches high and was tightly fitted against the fins. Sufficient space was left under the tube for the passage of the ignition cable to the rear spark plug. The lower end of the duct was fastened to the cylinder by a 1/4-inch-diameter stud screwed into the boss. In order to eliminate possible chafing or failure of the stud that might be caused by vibration, a rubber grommet was inserted into the baffle around the stud. Baffle B increased the weight of the cylinder-baffle assembly 0.90 pound. A sketch of ducted baffle B installed on a rear-row cylinder is shown in figure 3.

APPARATUS AND INSTRUMENTATION

The engine used for the tests was an 18-cylinder, two-row radial, air-cooled engine with a normal power rating of 2000 brake horsepower at 2400 rpm and was equipped with a single-stage, single-speed supercharger with a gear ratio of 6.06:1. Fuel conforming to AN-F-28 specifications was metered into the combustion air by means of a standard injection-type carburetor and spray bar. A torquemeter with a reduction-gear ratio of 20:7 was installed on both the test-stand and flight installations.

Test-stand installation. - The test engine was installed on an engine-propeller test stand and cooling air was drawn across the engine by a suction system capable of producing pressure drops up to 17 inches of water. The cooling-air pressure drop was taken as the difference between the total pressure between fins at the baffle inlet and the static pressure behind the baffle cowl ring and was measured across a cylinder that had no baffle changes. Cooling-air temperature was measured by three equally spaced thermocouples located 6 inches ahead of the front-row cylinders. Combustion air at 100° F (±5° F) was supplied by a centrifugal blower. The fuel-air ratio was determined by a chemical analysis of exhaust-gas samples from individual cylinders.

The engine temperatures were measured by iron-constantan thermocouples located at the following five positions on each cylinder: exhaust-valve seat, rear spark-plug gasket, rear spark-plug boss, front spark-plug boss, and rear middle barrel. The exhaust-valve-seat thermocouple (fig. 4) was located in the region of the maximum cylinder temperature. A specially designed jig was used in drilling the hole for this thermocouple in order that the position would be the same for all cylinders.

Flight installation. - The left outboard engine of the test airplane was selected for the baffle tests and sufficient instrumentation was installed to allow collection of the most pertinent data. The engine cylinder-head temperatures were measured by rear spark-plug-gasket thermocouples on all cylinders and by thermocouples installed to measure the temperature of the exhaust-valve seat of the rear-row cylinders. The rear-row exhaust-valve-seat thermocouple was located in the same position as for the test-stand installation (fig. 4). The combustion-air temperature was measured by two thermocouples in the elbow leading to the carburetor and the free-air temperature was obtained by using a calibrated thermocouple located near the left-wing tip. The average engine fuel-air ratio was computed from the fuel flow, which was measured with a rotameter, and from the combustion-air weight, which was obtained from a calibration of the carburetor uncompensated metering pressure. The cowl-flap position was determined by the use of an electrical position transmitter and indicator.

TEST PROCEDURE

Test stand. - In order to compare the performance obtained with the conventional and with the ducted head baffles, three series of tests at the following four specific engine operating conditions were undertaken with each baffle:

Brake horse-power	Engine speed (rpm)	Over-all fuel-air ratio	Cooling-air pressure drop (in. water)
1200	2000	0.071	10.5
1500	2200	.082	11.5
1700	2300	.085	11.8
2000	2400	.091	14.0

In the first series of tests, conventional baffles were installed on all cylinders; in the second series, baffle A was installed on cylinders 5, 7, and 15; and in the third series, baffle B was tested on cylinder 7 to afford a direct comparison between baffles A and B.

Flight tests. - Flight tests of the conventional baffles and baffle B were conducted at take-off, climb, and level flight according to the following flight and engine operating conditions:

Flight conditions	Brake horse-power	Engine speed (rpm)	Carburetor mixture setting	Pressure altitude (ft)
Take-off	2200	2600	Automatic rich	--------
Climb	1800	2400	--do----------	--------
Level flight	1475	2100	Varied	10,000

Flight tests were made first with conventional baffles on all cylinders and second with baffle B installed on cylinders 1, 3, 5, 15, and 17, which in previous tests had been determined the hottest cylinders at the level-flight conditions listed. Final tests were made with baffle B installed on all rear-row cylinders; data were obtained only for the level-flight conditions.

RESULTS AND DISCUSSION

The effect of the ducted baffles was observed by comparing the temperatures of particular cylinders fitted first with conventional baffles and then with ducted baffles. The reduction in the temperature of the exhaust-valve seat was used as a measure of the effectiveness of the ducted baffle. The effect of small variations in cooling-air temperature occurring between different tests was accounted for by the correction of reference 8. Cooling-air temperature variations did not exceed 10° F.

Preliminary Test-Stand Investigation

Baffle A. - In general the use of baffle A on cylinders 5, 7, and 15 considerably reduced the temperatures of both the exhaust-valve seat and the rear spark-plug gasket. The temperature reduction of the exhaust-valve seat was between 6° F and 47° F, whereas the reduction for the rear spark-plug gasket was between 40° F and 71° F. The temperature reductions for each cylinder at each of the operating conditions is given in the following table:

Engine power, bhp	1200			1500			1700			2000		
Cylinder	5	7	15	5	7	15	5	7	15	5	7	15
Exhaust-valve seat, °F	14	27	19	6	19	45	35	36	47	42	42	11
Rear spark-plug gasket, °F	51	53	46	46	47	65	66	64	69	71	66	40
Rear spark-plug boss, °F	57	61	59	54	57	80	76	72	84	85	77	56

Baffle B. - The use of baffle B on cylinder 7 reduced the temperature of the exhaust-valve seat between 27° F and 56° F and that of the rear spark-plug gasket between 85° F and 110° F. The reductions of exhaust-valve-seat temperature are large compared with those obtained with ducted baffle A. Inasmuch as ducted baffles A and B were both tested under the same conditions and on cylinder 7, it is possible to make the following direct comparison of the temperature reductions:

Engine power, bhp	1200		1500		1700		2000	
Baffle	A	B	A	B	A	B	A	B
Exhaust-valve seat, °F	27	47	19	27	36	54	42	56
Rear spark-plug gasket, °F	53	88	47	85	64	110	66	109
Rear spark-plug boss, °F	61	81	57	75	72	101	77	101

Effect of baffles on other temperatures. - The data in the previous section indicate that baffle B was more effective than baffle A in lowering the temperature of the rear-row exhaust-valve seat and that baffle B lowered the rear spark-plug-gasket temperature excessively in proportion to the decrease in the rear-row exhaust-valve-seat temperature. The reduction of the rear spark-plug-gasket temperature is therefore not an indication of the reduction of the internal critical temperature. The exhaust-valve-seat temperature is indicative of that particular area, but a reduction in this temperature must not be interpreted as a reduction of other critical temperatures as well. The temperatures of the front spark-plug boss and the rear middle barrel were not noticeably affected by the use of either ducted baffle.

Because the temperature reductions obtained with baffle B were considerably in excess of those obtained with baffle A and because baffle B handled only a slightly greater quantity of air, flight tests were conducted with baffle B to verify its effectiveness.

Flight Investigation

Baffle B on five hottest rear-row cylinders. - Although cylinder temperatures are not stabilized during take-off and climb, a significant comparison showing the effects of the ducted baffles may be made by plotting cylinder temperature against time for the take-off and climb conditions with conventional and ducted head baffles. Such a comparison is presented in figure 5 where the averages of the exhaust-valve seat temperatures of cylinders 1, 3, 5, 15, and 17 with and without baffle B are plotted against time from start of take-off until an altitude of 10,000 feet had been reached. The averages of the temperatures of the front-row rear spark-plug gaskets are included to show the similarity of the operating conditions of the two tests. When the cylinders were fitted with ducted baffle B, temperature reductions between 35° F and 70° F were obtained throughout take-off and climb, the most severe engine operating conditions.

The results of the level-flight test at 10,000 feet and 1475 brake horsepower using ducted baffle B on each of the five hottest rear-row cylinders are presented in figure 6. Average reductions of approximately 50° F and 97° F are shown for the exhaust-valve seat and the rear spark-plug gasket, respectively. The exhaust-valve-seat temperature reduction ranged from 37° F to 64° F. The temperature reductions for each of the five cylinders using ducted baffle B are tabulated for three over-all fuel-air ratios:

Cylinder	F/A = 0.065		F/A = 0.071		F/A = 0.079	
	Exhaust-valve seat (°F)	Rear spark-plug gasket (°F)	Exhaust-valve seat (°F)	Rear spark-plug gasket (°F)	Exhaust-valve seat (°F)	Rear spark-plug gasket (°F)
1	37	60	48	71	47	72
3	56	95	64	109	60	110
5	46	104	37	100	47	105
15	56	120	49	119	55	122
17	37	77	48	92	41	89
Average	46	92	49	98	50	100

The installation of baffle B on the five hottest cylinders of the engine resulted in a marked change in the temperature pattern. However, a large temperature spread existed in instances where some of the cylinders, which normally ran much hotter than the average, were so effectively cooled after installation of the special baffles that they operated at temperatures far below the mean.

Baffle B on all rear-row cylinders. - Because the results of tests with five ducted head baffles showed that no group of cylinders could be selected as the hottest over the range of engine operating conditions, level-flight tests at 10,000 feet were conducted with ducted baffle B on all rear-row cylinders. The results of these tests (fig. 7) show that the temperature of the exhaust-valve seat attained with ducted baffles was 42° F to 80° F below that attained with conventional baffles. The cylinder-temperature reductions for the rear-row exhaust-valve seats and the rear spark-plug gaskets are as follows:

Cylinder	F/A = 0.064		F/A = 0.077		F/A = 0.084	
	Exhaust-valve seat (°F)	Rear spark-plug gasket (°F)	Exhaust-valve seat (°F)	Rear spark-plug gasket (°F)	Exhaust-valve seat (°F)	Rear spark-plug gasket (°F)
1	43	70	59	84	42	72
3	66	90	80	122	64	110
5	64	110	49	108	56	105
7	69	152	60	130	66	124
9	49	(a)	48	(a)	52	(a)
11	46	108	48	119	49	104
13	57	138	57	134	57	124
15	72	128	64	138	66	125
17	50	84	51	100	48	94
Average	57	------	57	------	55	------
Maximum[b]	64	------	70	------	50	------

[a]Thermocouple failure.

[b]The amount the maximum temperature obtained with ducted baffles was reduced below the maximum temperature obtained with conventional baffles.

The substantial and consistent reduction of exhaust-valve-seat temperature obtained at all engine operating conditions tested demonstrates that ducted head baffles which conduct air to a specific portion of the cylinder surface are effective in reducing the internal cylinder temperature. This reduction depends, of course, on the existence of adequate internal heat-transfer paths between the internal location to be cooled and the external location to which the cooling air is applied.

SUMMARY OF RESULTS

From flight investigations of ducted head baffles of type B installed on the rear-row cylinders of an air-cooled radial engine, the following results were obtained for take-off, climb, and level-flight conditions:

1. For all flight tests the temperatures of the rear-row exhaust-valve seats were reduced an average of approximately 50° F. The reductions were reasonably consistent for all cylinders, ranging between 35° F and 80° F.

2. During level flight, the maximum temperature of the exhaust-valve seat obtained when using ducted baffles on all rear-row cylinders was reduced 50° F to 70° F below the maximum temperature of the exhaust-valve seat obtained with standard baffles on all rear-row cylinders.

CONCLUSION

Special ducted baffles may be used to reduce internal cylinder temperature when an adequate internal heat-transfer path exists.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, October 18, 1945.

REFERENCES

1. Weick, Fred E.: Drag and Cooling with Various Forms of Cowling for a "Whirlwind" Radial Air-Cooled Engine - I. NACA Rep. No. 313, 1929.

2. McAvoy, William H., Schey, Oscar W., and Young, Alfred W.: The Effect on Airplane Performance of the Factors That Must Be Considered in Applying Low-Drag Cowling to Radial Engines. NACA Rep. No. 414, 1932.

3. Beisel, Rex B., MacClain, A. Lewis, and Thomas, F. M.: The Cowling and Cooling of Radial Air-Cooled Aircraft Engines. SAE Jour., vol. 34, no. 5, May 1934, pp. 147-166.

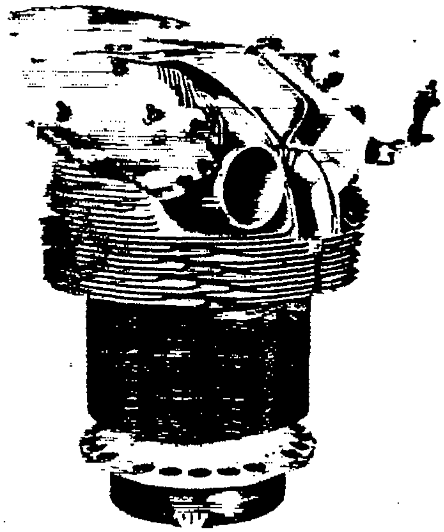
4. Schey, Oscar W., and Rollin, Vern G.: The Effect of Baffles on the Temperature Distribution and Heat-Transfer Coefficients of Finned Cylinders. NACA Rep. No. 511, 1934.

5. Schey, Oscar W., Rollin, Vern G., and Buckner, Howard A., Jr.: Comparative Cooling of Cylinders of Nonuniform Fin Width with Tight-Fitting Baffles and with Baffles That Provide Constant Flow-Path Areas. NACA ARR No. E4D21, 1944.

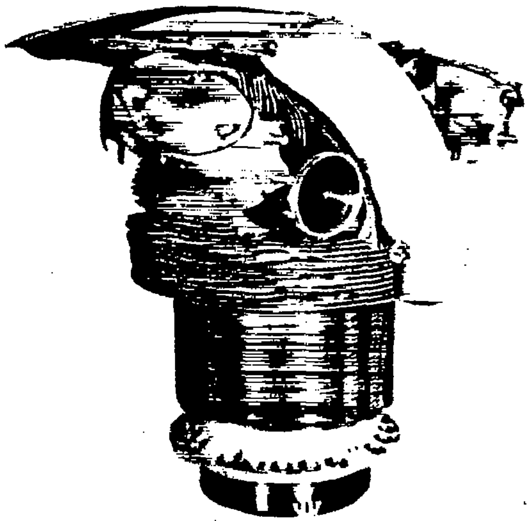
6. Silverstein, Abe, and Kinghorn, George F.: Improved Baffle Designs for Air-Cooled Engine Cylinders. NACA ARR No. 3H16, 1943.

7. Biermann, Arnold E., Cook, Harvey A., and Held, Louis F.: Improving Engine Cooling with Special Baffles. NACA ARR No. E5B05, 1945.

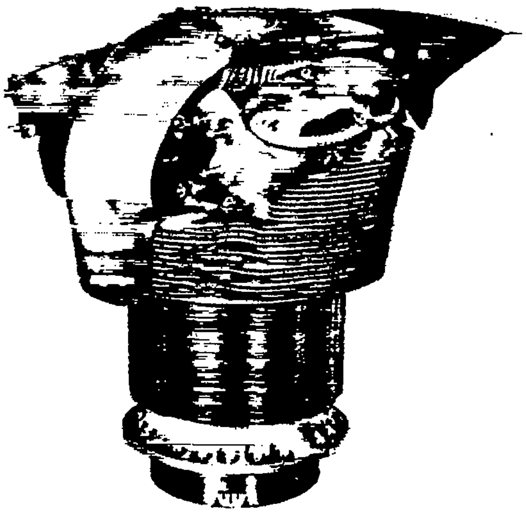
8. Schey, Oscar W., Pinkel, Benjamin, and Ellerbrock, Herman H., Jr.: Correction of Temperatures of Air-Cooled Engine Cylinders for Variation in Engine and Cooling Conditions. NACA Rep. No. 645, 1938.



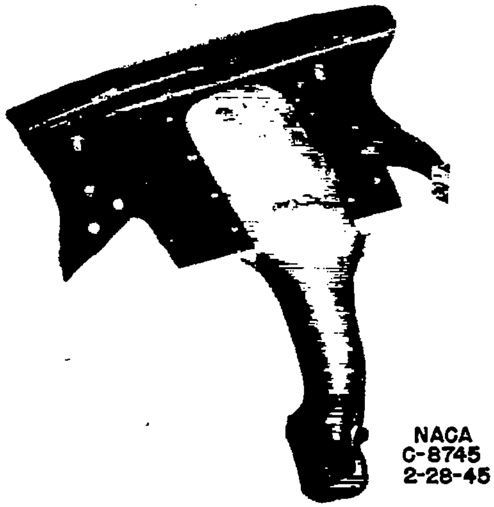
Left rear view of conventional head baffle



Left rear view of baffle A

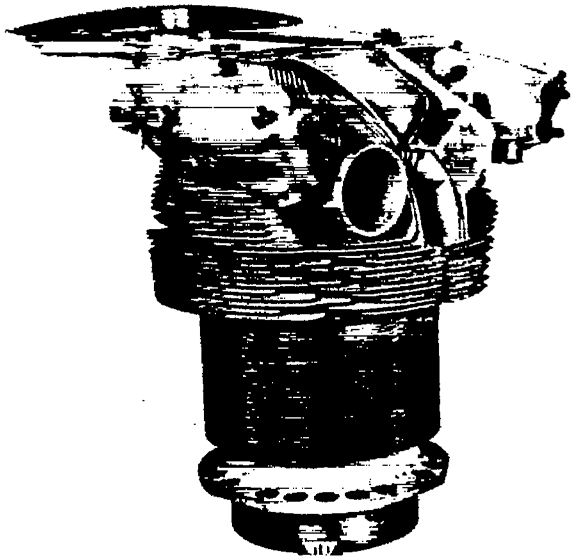


Right rear view of baffle A

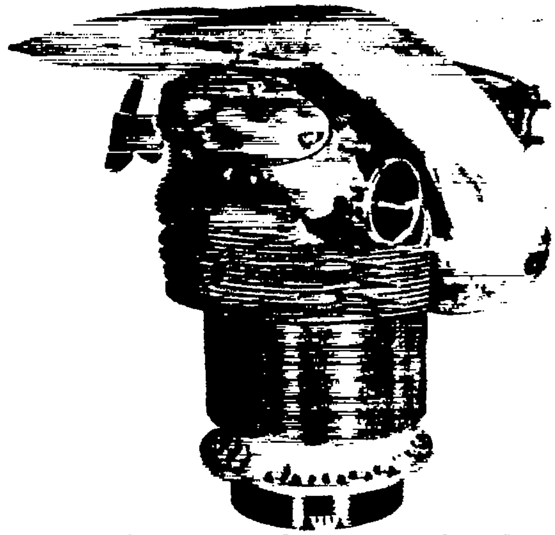


Baffle A

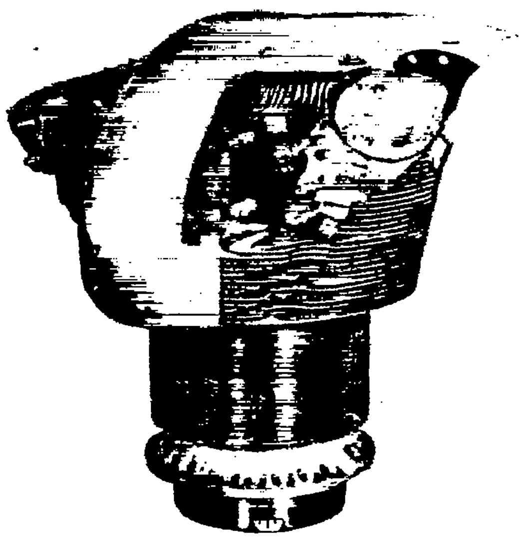
Figure 1. - Comparison of conventional head baffle with baffle A installed on a rear-row cylinder of an air-cooled engine.



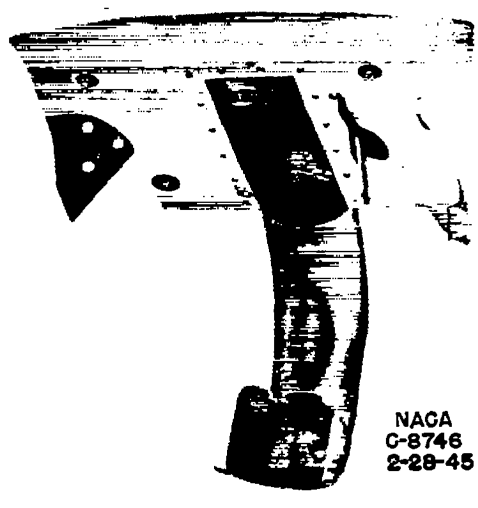
Left rear view of conventional baffle



Left rear view of baffle B



Right rear view of baffle B



Baffle B

Figure 2. - Comparison of conventional head baffle with baffle B installed on a rear-row cylinder of an air-cooled engine.

28+51A

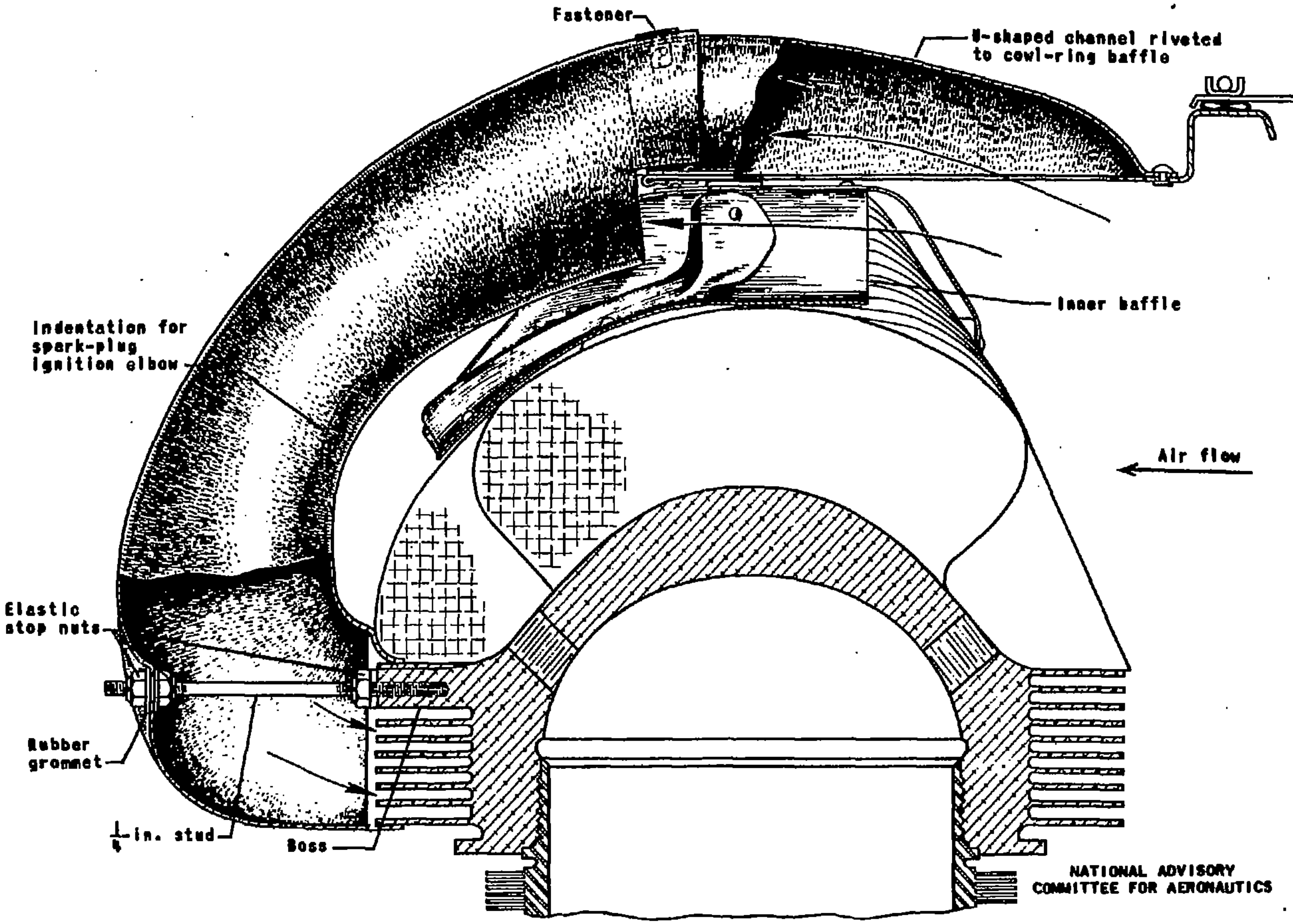
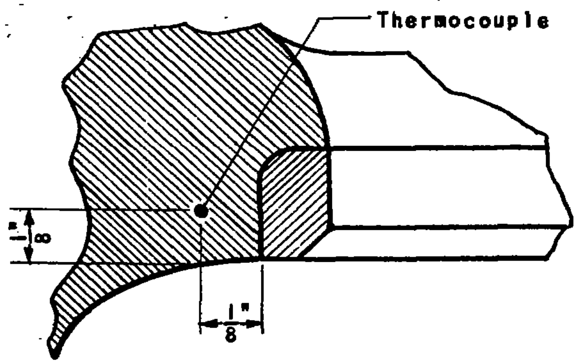
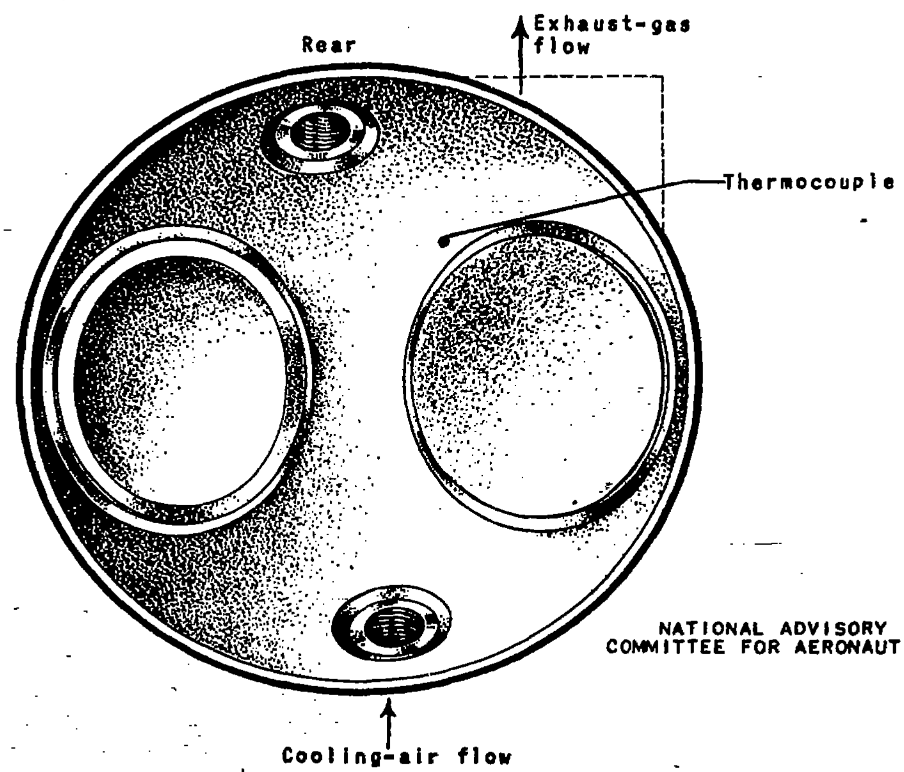


Figure 3. - Cutaway view of ducted baffle B installed on a rear-row cylinder head of an air-cooled engine.



(a) Section through valve seat.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(b) View inside barrel.

Figure 4. - Location of exhaust-valve-seat thermocouple on a rear-row cylinder of an air-cooled engine.

177-326

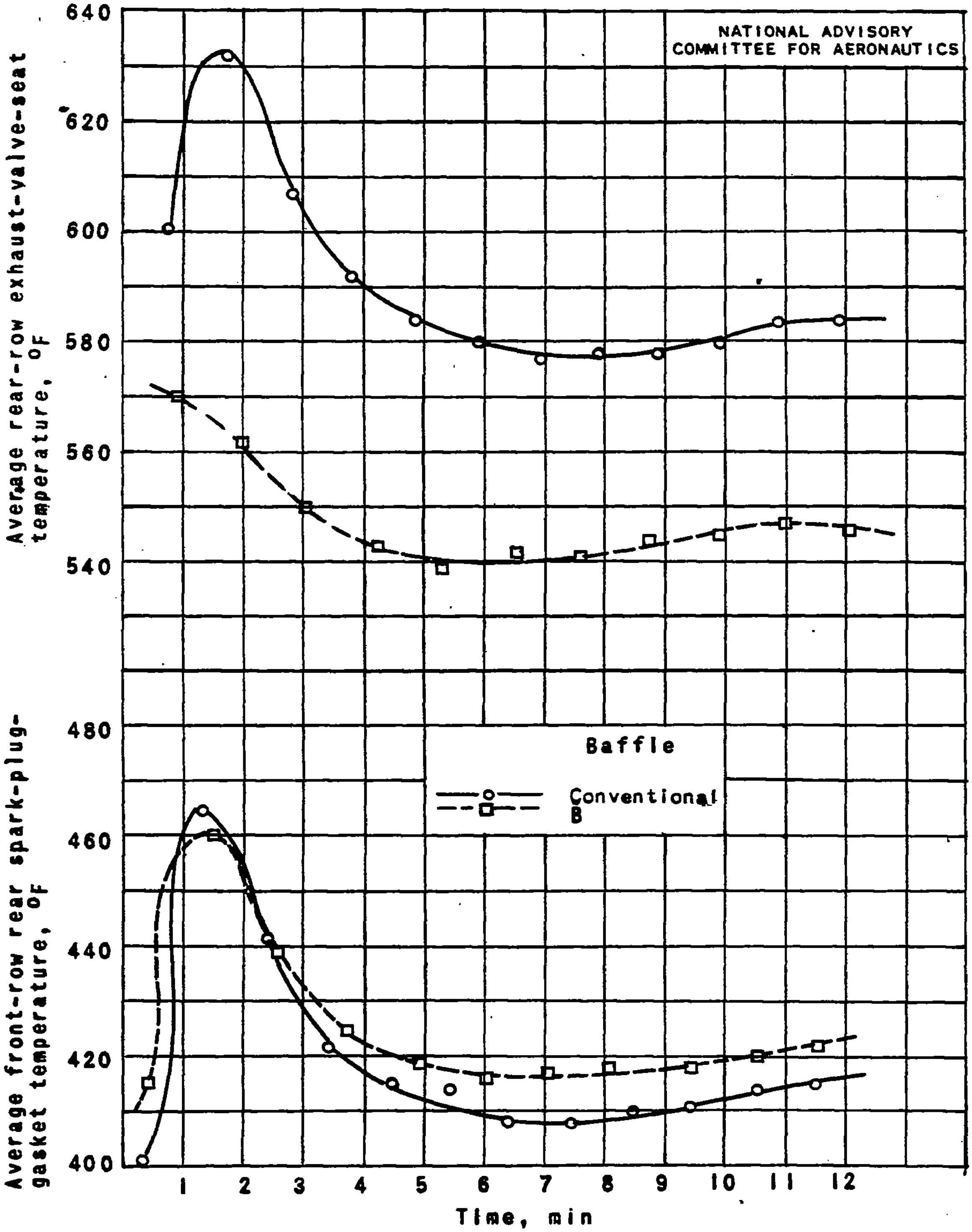
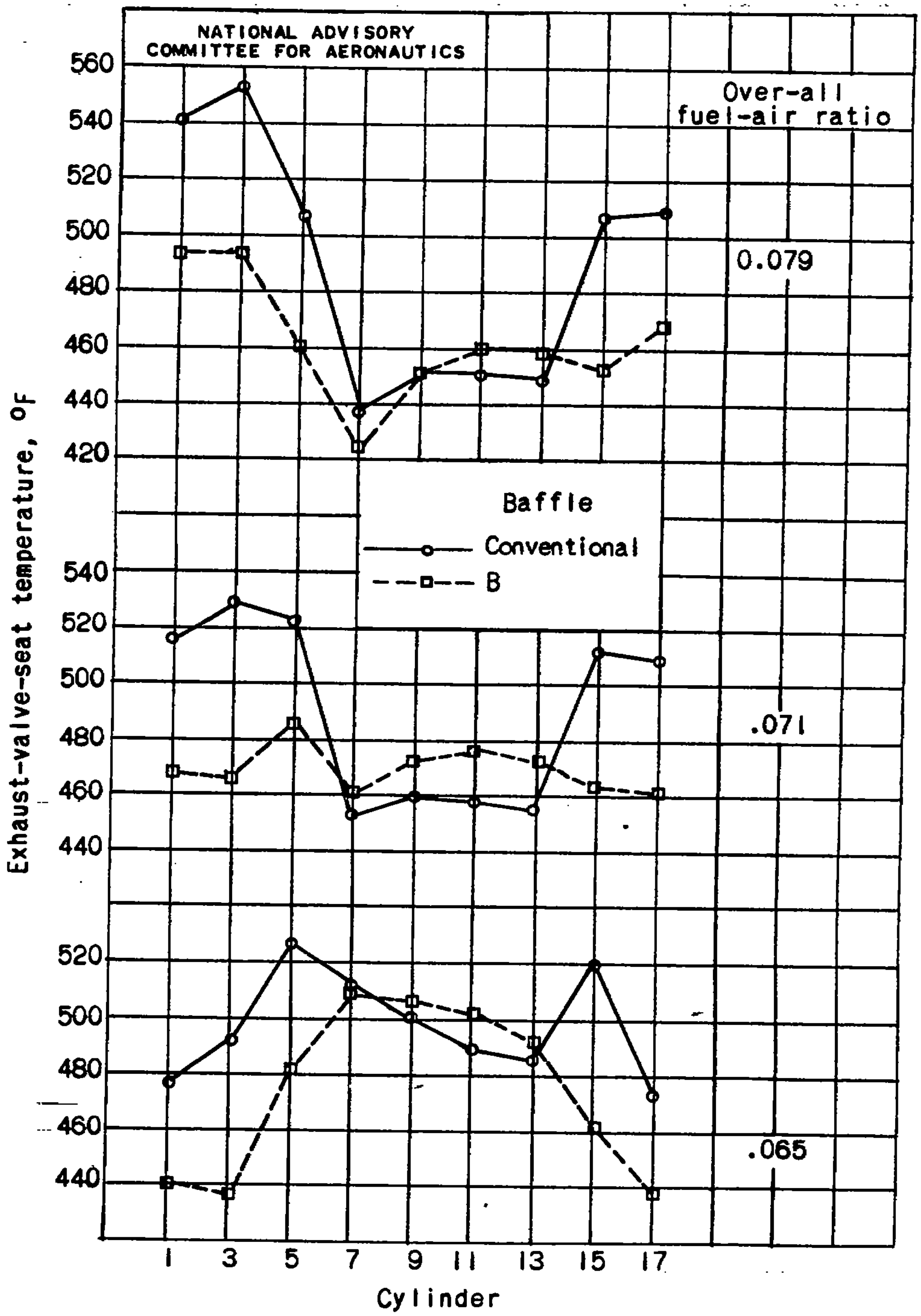
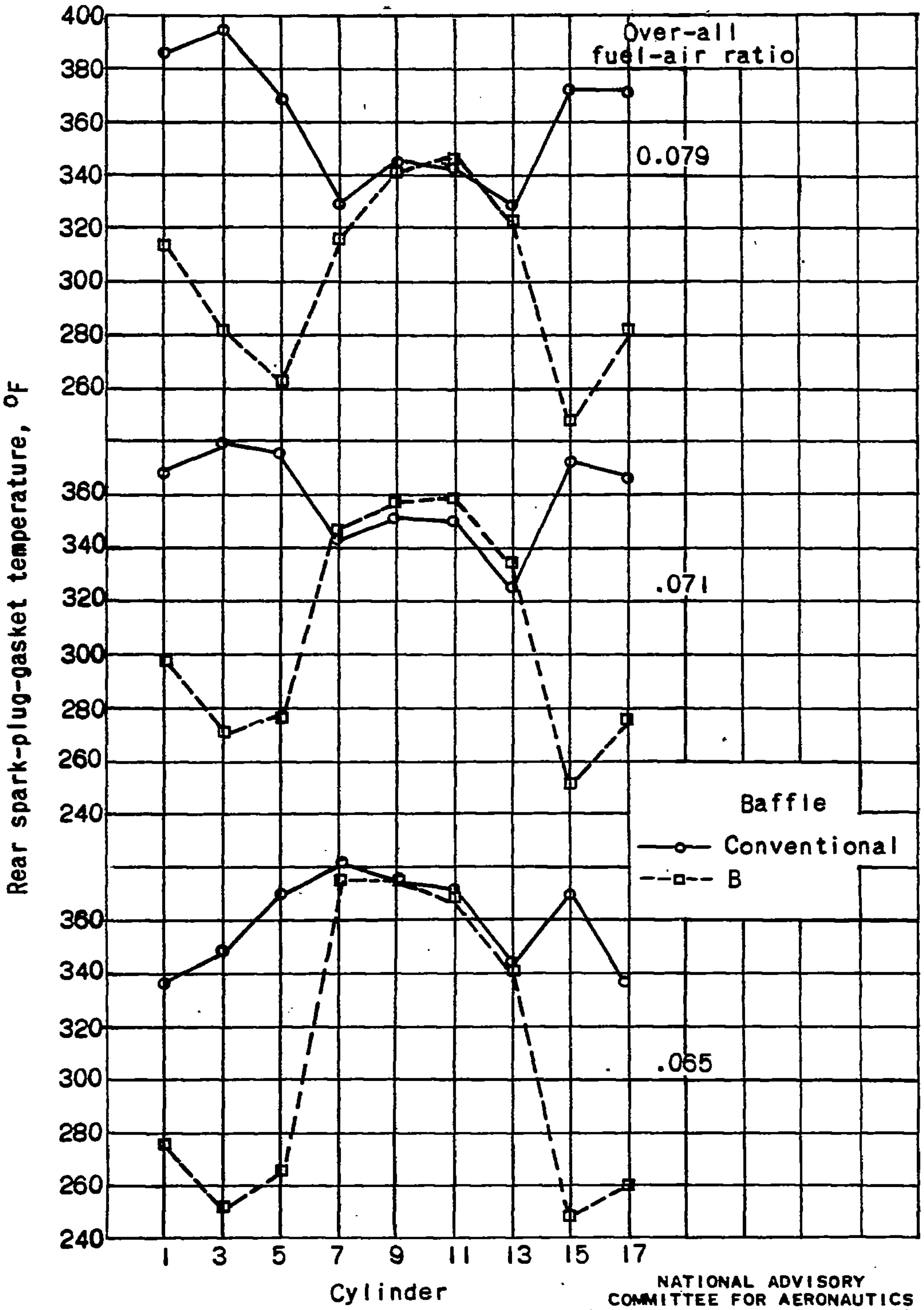


Figure 5. - History of average cylinder-head temperature of cylinders 1, 3, 5, 15, and 17 during take-off and climb.



(a) Exhaust-valve-seat temperature.

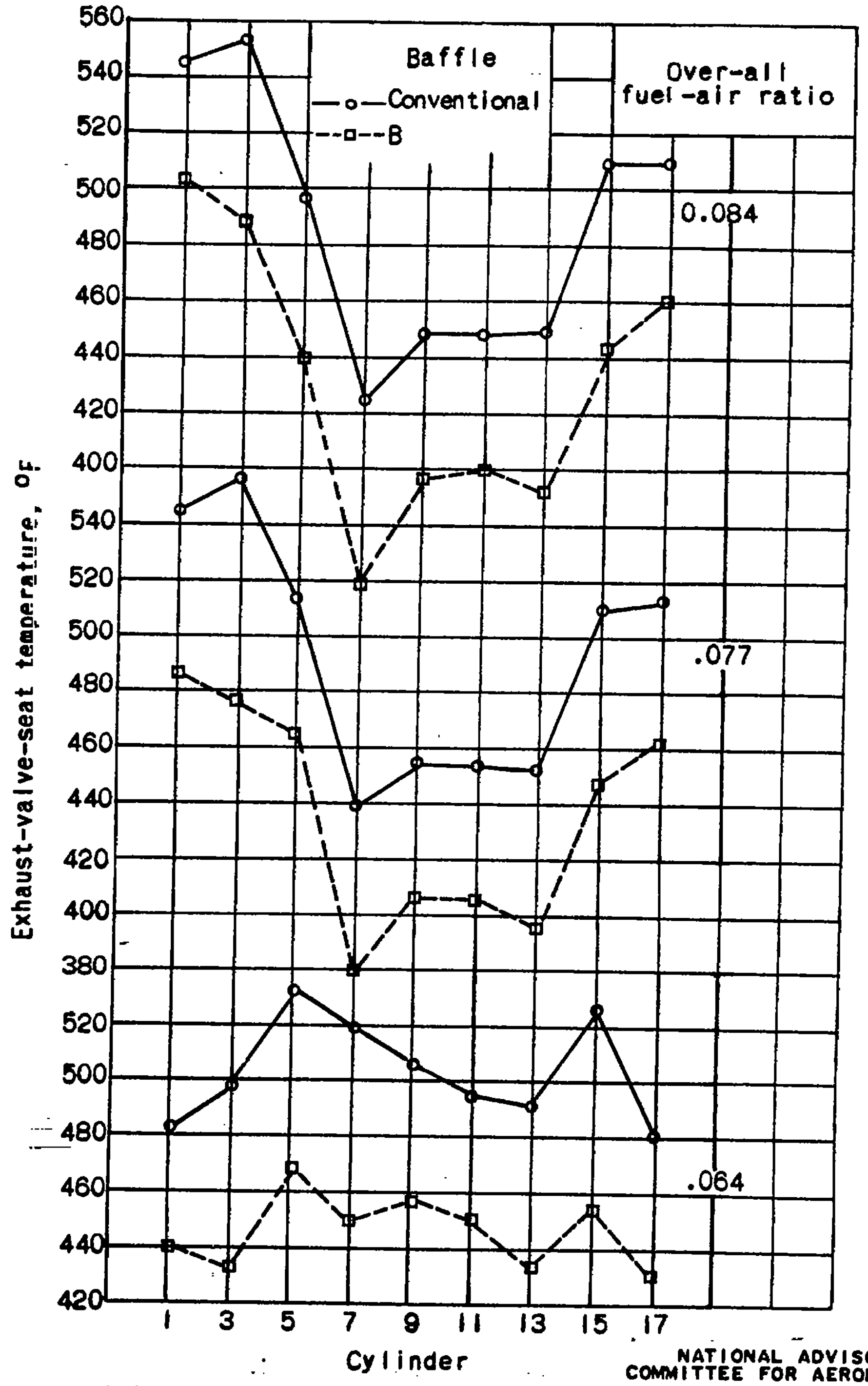
Figure 6. - Comparison of cylinder-head temperatures during level flight with conventional baffles and with baffle B on cylinders 1, 3, 5, 15, and 17. Brake horsepower, 1475; cowl-flap angle, 10°.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(b) Rear spark-plug-gasket temperature.

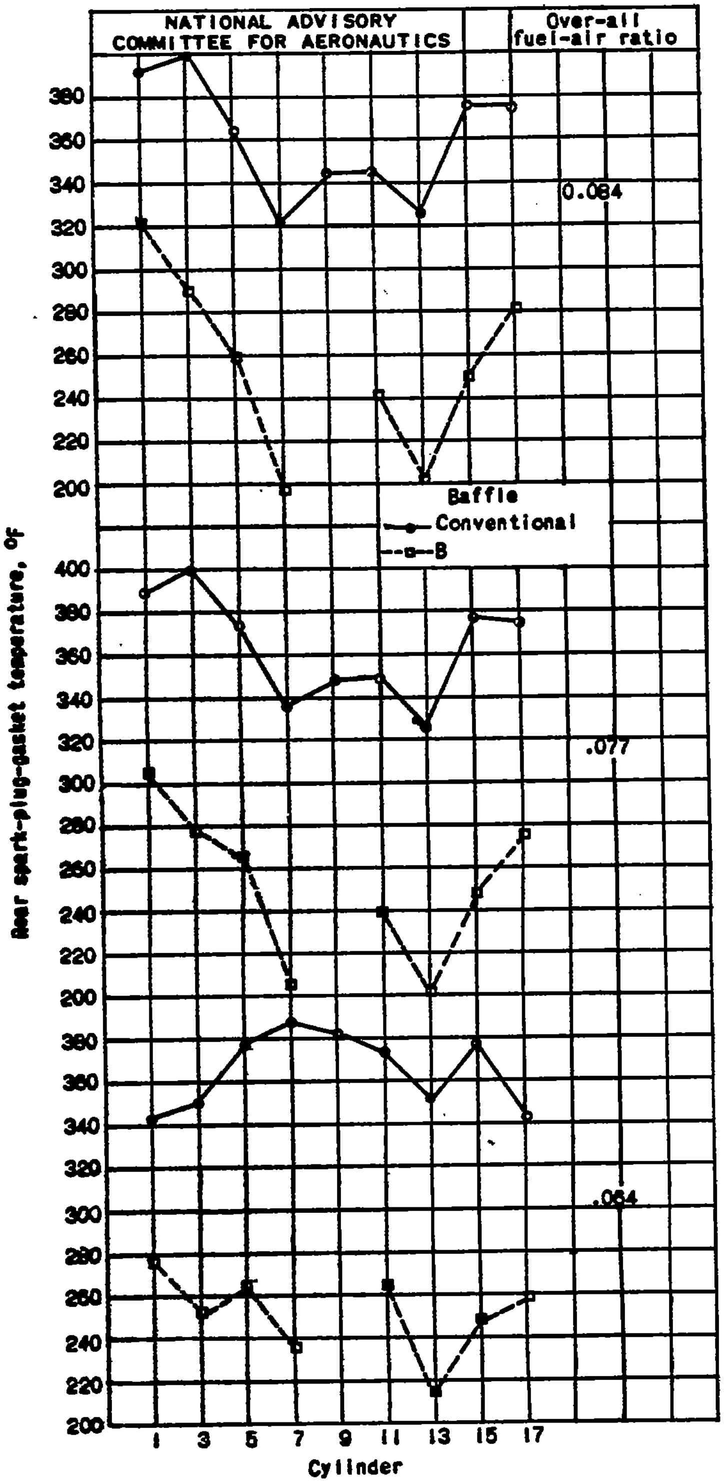
Figure 6. - Concluded.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(a) Exhaust-valve-seat temperature.

Figure 7. - Comparison of cylinder-head temperatures during level flight with conventional baffles and with baffle B on all cylinders. Brake horsepower, 1475; cowl-flap angle, 10°.



(b) Rear spark-plug-gasket temperature.

Figure 7. - Concluded.