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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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COOLING TESTS OF AN AIRPLANE EQUIPPED WITH AN NACA COWLING AND A WING-DUCT COOLING SYSTEM

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SUMMARY

Cooling tests were made of a Northrop A-17A attack airplane successively equipped with a conventional NACA cowling and with a wing-duct cooling system. The method of cooling the engine by admitting air from the propeller slipstream into wing ducts, passing it first through the accessory compartment and then over the engine from rear to front, appeared to offer possibilities for improved engine cooling, increased cooling of the accessories, and better fairing of the power-plant installation.

The results showed that ground cooling for the wing-duct system without cowl flap was better than for the NACA cowling with flap; ground cooling was appreciably improved by installing a cowl flap. Satisfactory temperatures were maintained in both climb and high-speed flight, but, with the use of conventional baffles, a greater quantity of cooling air appeared to be required for the wing-duct system.

INTRODUCTION

The increasing power of new designs of air-cooled engines with little change in frontal area has made it difficult to obtain cooling at low airplane speeds with the conventional cowling arrangements. This difficulty is particularly acute for installations with large propellers, in which the opening of the cowling may be blocked by the propeller hub and the blade shanks. Difficulties may also arise in cooling the accessory compartment. If no specific provision for cooling the accessory compartment is made, high temperatures of the intake system may decrease the engine power. In addition, it appears that the drag of the conventional cowling is often relatively high and that a better shape might be obtained.

The wing-duct cooling system appears to offer one solution of these problems. In such a system the cooling air is admitted into ducts through openings near the leading edge of the wing inside the propeller slipstream, is passed through the accessory compartment and the engine baffles from rear to front, and is ejected rearward through a suitable exit slot. By proper location of the duct entrances the slipstream can be utilized for low-speed cooling. The nose can be faired with or without a propeller spinner, and the oil radiator and the carburetor-air intake can be enclosed in the fuselage and supplied with air diverted from the ducts.

In order to test such an arrangement on an engine under actual conditions, a wing-duct cooling system was installed on a Northrop attack airplane (Air Corps designation A-17A) borrowed from the Army Air Corps. Tests were made of the airplane with the original NACA cowling and with the wing-duct system. When the airplane was equipped with the wing-duct system, several incidental improvements in fairing were made. Because it was impossible to analyze the separate effects of the various modifications on the drag, the results of the tests relate primarily to cooling rather than performance.

APPARATUS

Airplane

The A-17A airplane with the original NACA cowling installation is shown in figures 1, 2, and 3. The external arrangement of the carburetor-air intake and the oil radiator may be noted. The engine exhaust was through a single outlet located on the right side of the fuselage. The flow of cooling air was regulated by a conventional outward-opening cowl-flap installation. With the flaps closed to the limit, the width of the exit slot measured across the minimum distance was about 2 inches. With flaps fully open, the effective opening was large; but it is difficult to assign a significant value to the slot width because of the openings at the flap hinge line and between the sections of the flap, which may be seen in figure 3. The principal characteristics of the airplane are as follows:

Airplane

Type - Northrop attack, U.S. Army designation A-17A

Span - - - - - - - - - - - - - - - - - - - 47 feet 9 inches

Wing area - - - - - - - - - - - - - - - - 362 square feet

Length - - - - - - - - - - - - - - - - - - 31 feet 8 inches

Average gross weight as tested - - - - - 7150 pounds

Engine

Type - Pratt & Whitney model R-1535-13; 14-cylinder, 2-row radial, rated 750 horsepower at 2500 feet at 2500 rpm.

Compression ratio - - - - - - - - - - - - - - - - - 6.7

Blower ratio - - - - - - - - - - - - - - - - - - - 8.7

Propeller-shaft ratio - - - - - - - - - - - - - - - 4:3

Recommended maximum cylinder head temperatures:

For 90 seconds in take-off or climb - 550° F (288° C)

Continuous high speed or climb - - - 500° F (260° C)

Continuous cruising - - - - - - - - - 455° F (235° C)

(It should be noted that these recommended values are actual head temperatures, whereas the test results are given in terms of temperature above that of free air.)

Propeller

Type - Three-blade, Hamilton Standard, controllable, two-position; Hamilton Standard drawing number 6101A-6.

Diameter - - - - - - - - - - - - - - - - 9 feet 6 inches

Settings at 42-inch station - - - - 19.5° and 26°

Wing-Duct Cooling System

Diagrams of the wing-duct cooling system are shown in figures 4 and 5. Figures 6 and 7 are photographs of the airplane with the wing-duct cooling system installed. The duct entrances were located ahead of the leading edge of the wing at the retracted position of the wheels, as shown in figure 8, with the mouths at approximately two-thirds the propeller radius. The entrance lips of the ducts were well rounded and the duct housings were faired into the fuselage and the wing. The completed duct installation with wheels retracted is shown in figure 9. Each duct made one 90° turn, in which guide vanes were placed, just before reaching the accessory compartment. The cooling air was admitted to the accessory compartment through a set of diffusing vanes designed to minimize expansion losses accompanying the large increase in cross-sectional area of the flow at this point. The air passed forward over the accessories and through the engine baffles from rear to front, was reversed in direction at the propeller spinner, and was ejected rearward through the exit slot at the trailing edge of the spinner.

The propeller spinner was of relatively large diameter, covering the propeller hub and most of the portion of the blade shanks that are of poor airfoil shape. It was closed at the rear by a plate behind the propeller blades. This plate and the trailing edge of the spinner formed the forward part of the cooling-air exit slot. The rearward part of the exit slot was formed by the non-rotating section of the cowling to the rear. This section moved back and forth to vary the width of the exit slot and thus to regulate the flow of cooling air. Such an arrangement performs this function without destroying the smooth shape, as outward-opening cowl flaps do. The slot width, measured across the minimum distance, could be varied from 0.6 to 2.7 inches. For one of the ground-cooling tests, a strip of metal was attached to the cowling to simulate a cowl flap at the trailing edge of the spinner, as shown in figure 4.

The internal arrangement of the cooling system and the accessories with the wing-duct system was considerably different from that with the NACA cowling. The primary modification was the replacement of the original engine baffles. The baffles installed for the wing-duct tests covered about as much of the cylinders as did the original ones, but they were applied to the front of the cylinders instead of to the rear because of the reversal in direction of the cooling air flow. They followed the contour of the cylinders closely and fitted more tightly than the original set. Particular care was taken to eliminate any openings, other than the space between the cooling fins, through which the air might flow past the cylinders. The inner cowling and the partition between the engine and the accessory compartment in the original installation were removed. The exit slot for the accessory compartment was eliminated.

The original exhaust system was entirely removed and was replaced by a new one with two outlets, one on each side of the fuselage. The original exhaust manifold was relatively large because it collected the exhaust from all the cylinders. The manifold was divided into two separate smaller systems in order that the engine cooling air could pass with less resistance and preheating than was possible with the original arrangement. The two modified outlets had about the same total area as the original outlet, but they protruded less and probably had a lower drag. The manifolds and the outlets were partly enclosed in metal shrouds open to the accessory compartment at the inner ends and to the air stream at the outer ends. The pressure in the accessory compartment forced air through the space between the shrouds and the manifolds and outlets. This air jacket was intended to prevent the cooling air from being excessively heated in passing over the exhaust pipes before reaching the cylinders. As the results show, this arrangement was not completely effective, but equipping the airplane with a better system for these tests was not feasible because of the extensive revision required. The shrouding and the outlet of the right-hand exhaust system may be seen in figure 8.

The original carburetor-air scoop and intake system were removed. In the wing-duct system, air was supplied to the carburetor through a walled-off section of the left duct. No provision was made for heating the air before it reached the carburetor as had been done in the original installation.

The lower part of the accessory compartment cover was rebuilt to enclose the oil radiator, as shown in figure 9. The entrance end of the oil radiator was left open to the interior of the accessory compartment; the exit end opened into the air stream through a short duct, so that the pressure in the accessory compartment forced cooling air through the radiator.

Instrument Installation

Cylinder temperatures were measured by thermocouples at the front and the rear spark-plug bosses and at the front and the rear of the barrels, midway between the head and the flange, on cylinders 4, 5, 11, and 12. The thermocouples at the plug bosses were inserted in the metal and those on the barrels were welded to the cylinder walls between the fins. The cylinders were numbered in the direction of propeller rotation beginning with the uppermost, which was in the rear bank. Thus, cylinders 4 and 5 are on the right side of the engine, 11 and 12 on the left side, 4 and 12 in the front bank, and 5 and 11 in the rear bank.

Electrical resistance thermometers with suitably located bulbs were used to measure the temperatures of the accessory compartment, the carburetor-intake air, and the cooling air after passing over the accessories and after passing through the engine baffles. Total-pressure tubes were used to determine the pressure of the cooling air in the front and the rear of the engine cylinders and inside the mouth of each duct just forward of the guide vanes.

In addition to the usual service instruments, a sensitive recording statoscope, a recording tachometer, and an NACA air-speed recorder connected to an NACA swiveling pitot-static head were installed for the tests.

METHODS AND TESTS

Ground Cooling Tests

Time histories of cylinder and oil temperatures for full-throttle operation of the engine on the ground appear to be the best measures of the ground-cooling characteristics. The engine was started when cold and the throttle was fully opened as soon as the engine had idled long enough for the oil temperature and pressure to reach the values recommended in service. The propeller was kept at the low blade-angle setting (19.5°) and the mixture was held full rich during the runs. Runs were made with the cowl flaps fully open on the NACA cowling and with an exit slot width of 2.7 inches on the wing-duct system; an additional run was also made after the installation of a simulated cowl flap on the wing-duct system.

Climb Cooling Tests

Full-throttle climbs were made with the propeller at the low blade-angle setting and with the air speed approximately that for best rate of climb to find the climb-cooling characteristics. The throttle was fully opened at a pressure altitude of 2500 feet, which was the critical altitude of the engine. A steady climb was then established and readings were begun at 3000 feet. Three sets of temperature values were taken in the climb to determine the trend. The mixture was kept full rich throughout the climb in order that this condition of the test might be reproducible from run to run. Such a procedure is not representative of service operation, but it would have been virtually impossible to make any other adjustment reproducible in various flights. In an effort to impose the most severe operating conditions on the wing-duct system, however, one test was conducted in which an attempt was made to adjust the mixture continuously for best power operation. In the climbs with the NACA cowling the cowl flaps were fully open, and in those with the wing-duct system the exit slot width was 2.7 inches. The cowl flap installed on the wing-duct system for one of the ground cooling tests was not used in any flight.

High-Speed Cooling Tests

In order to determine the cooling characteristics in the high-speed condition, data were taken in full-throttle, level flight with the mixture adjusted for best power. After steady conditions had been established, records were taken. Runs were made with the cowl flaps fully closed for the NACA cowling and with exit-slot widths of 1.3 and 2.7 inches for the wing-duct system. The reasons for choosing these two values of the exit-slot width will be discussed later.

Maximum-Speed Tests

The maximum speed of the airplane appears to be the best over-all criterion of possible changes in drag, propeller efficiency, and engine power. In order to determine the speed, a number of full-throttle runs were made at a density altitude of 10,000 feet. In these runs the mixture was adjusted for best power, and considerable care was taken to obtain steady conditions and to maintain level flight. All maximum-speed runs were made on the NACA cowling with the cowl flaps fully closed and on the wing-duct system with exit-slot widths of 1.3 and 2.7 inches.

Reduction of Data

In the reduction of the data on cylinder and accessory temperatures, the values were referred to free-air temperature as the datum. The measured values of impact pressure were converted into true air speed by the usual method. The observed air speeds and the engine speeds from the maximum-speed tests were adjusted to 10,000 feet on a density-altitude basis, because the runs were not all made at exactly the desired altitude. Such a procedure is believed sufficiently accurate for these tests, although maximum speed is not a function of density altitude alone.

The pressure drop across the engine was reduced to coefficient form by the relation

$$\frac{\Delta p_e}{\rho n^2 D^2}$$

where Δp_e is the pressure drop across the engine; ρ, the air density; n, the propeller rotational speed; and D, the propeller diameter in any consistent system of units. A similar coefficient $p_e/\rho n^2 D^2$ was set up for p_e, the pressure inside the mouth of the ducts, and a coefficient $\Delta p_T/\rho n^2 D^2$ was set up for Δp_T, the total pressure drop across the ducts and the engine excluding any loss at the duct entrance.

RESULTS AND DISCUSSION

Ground Cooling

The temperature data obtained in full-throttle ground runs are presented in figures 10 and 11. (Temperature data at some points are missing because of thermocouple failure.) The time histories of cylinder temperatures for the NACA cowling indicate that, after 6 minutes, about half of the temperatures had become steady while the rest were still increasing. The maximum head temperature was about 455° F above free air. For the wing-duct system with an exit slot of 2.7 inches, a steady state was reached in about 8 minutes, with a maximum head temperature of 445° F above free air. The installation of the cowl flap on the wing-duct system improved the ground-cooling characteristics. The cylinder temperatures rose more slowly and became constant at a lower value than with the NACA cowling, reaching a maximum of about 425° F above free air in approximately 9 minutes. The increase in oil temperature was also appreciably less rapid than with the NACA cowling after 4 minutes of operation, as shown in figure 11.

A direct comparison of the three arrangements on the basis of time is slightly unfair to the NACA cowling, because the time is plotted from the full opening of the throttle as zero and the engine was idled somewhat longer previously to that time with the NACA cowling. This procedure resulted in higher temperatures at zero time, as shown in figures 10 and 11. From the equilibrium temperatures, however, it appears that the wing-duct system without cowl flap is a small improvement over the NACA cowling and that the addition of a cowl flap to the wing-duct system renders it considerably better. This comparison holds for the system as actually tested. The exhaust shielding, however, was not completely successful and the cooling air was appreciably heated before reaching the cylinders. If this effect could have been eliminated, the cylinder temperatures for the wing-duct system would have been reduced as much as 40° F. The wing-duct system would then afford much better ground cooling than the NACA cowling.

If comparison is made between individual cylinder temperatures for the two cooling systems, the effect of reversing the direction of cooling-air flow should be taken into account; that is, the comparison should be made between readings of thermocouples similarly disposed relative to the air flow rather than between the readings of the same thermocouple for the two arrangements.

The time histories of the oil temperatures for the ground runs are shown in figure 11. The temperature given was the actual temperature of the oil entering the engine; it was not referred to free air. The higher initial temperature at the opening of the throttle with the NACA cowling should be noted in considering the data. It thus appears, from the slopes of the curves, that the cooling as shown by the rate of change of temperature with time was about the same for the NACA cowling as for the wing-duct system without cowl flap and that the cooling was improved by the addition of a cowl flap to the wing-duct system. These results are in agreement with the indications of the cylinder temperatures.

A particularly valuable characteristic of the wing-duct system with respect to oil cooling is that any reasonable size of oil cooler could be installed without increasing the external drag of the airplane because the oil cooler can be enclosed in the accessory compartment.

Climb and High-Speed Cooling

Typical results of the climb-cooling tests and of the high-speed cooling tests are shown in tables I and II, respectively. In table I the trend of any particular temperature with increasing time and altitude is shown by the variation in the readings from left to right in the corresponding row; the three sets of readings for each climb were taken successively during the run. After the data in table II had been obtained, it was found that the values for the NACA cowling were from a run in which the speed was several miles an hour less than the probable maximum, but the temperatures are believed not to have been materially influenced.

The climb cooling was satisfactory. As shown in table I, the engine cooling of the two systems in the full-rich climbs was about the same, with the maximum temperature slightly higher for the wing-duct system. The increase in temperature for the best-power climb was not large. In the wing-duct system the cooling air was preheated in passing over the accessories and the exhaust system. If this effect could be obviated by a more complete shielding or by a rearrangement of the exhaust, the cooling with wing-duct system would be better than with the NACA cowling.

In full-throttle, level flight (table II) an exit-slot width of 2.7 inches gave substantially correct cooling for the wing-duct system in spite of the preheated air. Closing the exit slot to 1.3 inches raised the maximum head temperature an amount approximately equal to the preheating. Elimination of the preheating would reduce the temperature by that amount for the same exit-slot width. These two settings of the exit slot were therefore chosen as the actual and the ideal adjustments for satisfactory cooling.

Bringing the cooling air directly into the accessory compartment considerably lowered the temperature of the compartment, as shown in the tables. The temperature of the carburetor-intake air was also less for the wing-duct system, but this reduction may have been due to the elimination of the carburetor-air heater rather than to a change in accessory cooling.

The pressure drop across the engine in high-speed, level flight (table II) was increased from 6.6 inches of water for the NACA cowling to 10.3 inches of water for the wing-duct system with a 1.3-inch exit slot. Although these conditions represent practically equivalent cooling, the difference in pressure drops is not a measure of the change in quantity of cooling air required because the conductivity of the engine was reduced by the new baffles. The fact that the temperature rise of the cooling air through the baffles was less for the wing-duct system than for the NACA cowling indicates an increase in the quantity of air for the wing-duct system. Because the power expended in cooling the engine is proportional to the product of the rate of cooling-air flow and the pressure drop, it appears that the cooling power was greater for the wing-duct system. It should be noted that the nature of the cooling process is different for the two systems. For the NACA cowling, the front of the engine is largely cooled by turbulent air, part of which may flow over the front of the engine and then outside the cowling; that is, the amount of air actually used in cooling the engine may be greater than that passing through the baffles. For the wing-duct system, the cooling was nonturbulent and all the cooling air passed through the baffles. A different type of baffle designed for nonturbulent cooling would probably have been more efficient.

Pressure Coefficients

The pressure data are summarized in figure 12 in the form of the previously derived coefficients. Except for the ground points, the pressures will be given in this discussion in terms of the dynamic pressure, q, at $V/nD = 1.05$ approximately. The coefficient based on p_e, the pressure inside the duct mouth, was about 0.67 (or $p_e/q = 1.21$) in the high-speed condition and was not appreciably affected by the exit-slot width or by the presence of the cowl flap. Slot width or cowl flaps merely regulate the flow of the cooling air through the system, and the accompanying variation in quantity apparently was too small to influence appreciably the flow conditions at the duct mouth.

The coefficient Δp_T of total pressure drop across the ducts and engine (exclusive of any loss at the duct mouth) decreased from about 0.60 (or $\Delta p_T/q = 1.09$) with a 2.7-inch exit slot to about 0.42 (or $\Delta p_T/q = 0.76$) with a 1.3-inch exit slot in the range of V/nD for high-speed flight. The effect of the cowl flap on the pressure for ground operation, $V/nD = 0$ is shown by the increase in the coefficient from 0.16 to 0.22 when the flap was added. Both p_e and Δp_T are the average values from both ducts, which showed no significant difference.

The coefficient of pressure drop across the engine, Δp_e presents a comparison of various exit-slot arrangements for both the NACA cowling and the wing-duct system. In the high-speed range, the wing-duct system gave values of 0.50 (or $\Delta p_e/q = 0.91$) and 0.35 (or $\Delta p_e/q = 0.63$) for exit-slot widths of 2.7 and 1.3 inches, respectively, as compared with values for the NACA cowling of 0.36 (or $\Delta p_e/q = 0.65$) with the cowl flaps open and 0.27 (or $\Delta p_e/q = 0.49$) with the flaps closed. The effect of the wing-duct system for the ground condition was marked. The coefficient increased from 0.02 for the NACA cowling with the flaps open to 0.11 for the wing-duct system with a 2.7-inch exit slot and to approximately 0.15 with the addition of the cowl flap.

It should be noted that, in the installation of a wing-duct system on an airplane to which it is more easily adapted than to the A-17A, such as a large multiengine airplane, the problem of duct design would be considerably easier. The duct losses could be made substantially smaller than for the A-17A, and greater engine pressure drops would then be available or, if the engine pressure drop were held constant, the cooling power could be accordingly reduced.

Maximum Speed

The results of the full-throttle runs are listed in table III. The quantities listed in the column headed "Observed" are the values actually found in the runs. The quantities tabulated under the heading, "Adjusted to 10,000 feet," have been corrected to that altitude, as mentioned in the section on Reduction of Data. The data appear fairly consistent, with the exception of two evidently low values for the NACA cowling. The probable mean values of the speeds are estimated as 203 miles per hour for the NACA cowling, and 210 and 213 miles per hour for the wing-duct system with exit-slot widths of 2.7 and 1.3 inches, respectively. It was not possible to evaluate the effect of the wing-duct system on the drag of the airplane from these data because the maximum speed was affected by a number of other changes whose influences could not be separated. The increase in maximum speed appears to be the combined result of decreased drag, higher propeller efficiency, and possibly greater engine power.

CONCLUDING REMARKS

The ground cooling for the wing-duct system without cowl flap was better than for the NACA cowling with flap; with a cowl flap added the ground cooling was appreciably improved. Satisfactory temperatures were maintained in both the climb and the high-speed conditions, but a larger quantity of cooling air appeared to be required for the wing-duct system with the conventional type of baffle used. It was impossible to evaluate the merits of the wing-duct system with respect to drag because of the number of other changes whose effects could not be separated.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 22, 1941.

TABLE I. - COOLING IN FULL-THROTTLE CLIMBING FLIGHT WITH VARIOUS COOLING-SYSTEM ARRANGEMENTS ON A-17A AIRPLANE

				NACA cowling			Wing-duct cooling system					
Location of thermocouple (F, front; R, rear)	Cylinder number	Cylinder bank	Side of engine	Mixture full rich; cowl flaps fully open; pressure altitude, 3000 to 10,000 ft; free-air temperature, 36° to 31°F			Mixture full rich; exit-slot width, 2.7 in.; pressure altitude, 3000 to 9500 ft; free-air temperature, 51° to 40°F			Mixture adjusted for best power; exit-slot width, 2.7 in.; pressure altitude, 3000 to 10,300 ft; free-air temperature, 55° to 41°F		
				Cooling-air temperature rise over accessories, °F								
			Left	------	------	------	39	36	36	34	32	35
			Right	------	------	------	40	38	36	35	35	38
				Cooling-air temperature rise through baffles, °F								
			Left	55	72	72	57	57	54	50	56	58
			Right	68	89	90	57	60	60	53	58	63
				Accessory compartment, temperature above that of free air, °F								
				30	43	46	14	10	9	13	9	8
				Carburetor-intake air, temperature above that of free air, °F								
				19	22	22	10	6	6	11	5	6
				Temperature above that of free air, °F								
Barrel, F	4	Front	Right	215	235	220	300	310	305	295	305	325
Spark plug, F	4	--do---	--do-	340	360	335	395	405	390	390	405	430
Spark plug, R	4	--do---	--do-	365	390	375	350	375	380	385	395	425
Barrel, R	4	--do---	--do-	240	245	245	---	---	---	---	---	---
Barrel, F	5	Rear	--do-	195	200	190	250	265	270	270	275	290
Spark plug, F	5	--do---	--do-	315	310	305	320	320	335	340	345	365
Spark plug, R	5	--do---	--do-	395	385	370	385	375	375	380	385	415
Barrel, R	5	--do---	--do-	310	295	295	255	255	255	250	260	285
Barrel, F	11	--do---	Left	---	---	---	---	---	---	---	---	---
Spark plug, F	11	--do---	--do-	310	270	250	330	315	290	320	325	345
Spark plug, R	11	--do---	--do-	375	335	305	350	335	310	350	355	375
Barrel, R	11	--do---	--do-	---	---	---	---	---	---	---	---	---
Barrel, F	12	Front	--do-	205	185	180	270	280	280	280	290	320
Spark plug, F	12	--do---	--do-	300	245	235	335	320	310	340	360	385
Spark plug, R	12	--do---	--do-	340	310	280	335	315	300	335	355	380
Barrel, R	12	--do---	--do-	280	270	265	235	235	235	235	245	265

TABLE II. - COOLING IN FULL-THROTTLE LEVEL FLIGHT WITH VARIOUS COOLING-SYSTEM ARRANGEMENTS ON A-17A AIRPLANE

	Location of thermocouple (F, front; R, rear)	Cylinder number	Cylinder bank	Side of engine	NACA cowling	Wing-duct system	
Exit-slot width, in.-------					[a]2.0	2.7	1.3
Cooling-air pressure drop across engine, in. water					6.6	14.3	10.3
Density altitude, ft------					9000	10,070	10,070
True air speed, mph-------					192	212	215
Free-air temperature, °F--					8	42	42
Cooling-air temperature rise over accessories, °F							
				Left	--------	36	39
				Right	--------	35	38
Cooling-air temperature rise through baffles, °F							
				Left	76	42	60
				Right	80	47	56
Accessory compartment, temperature above that of free air °F							
					51	9	8
Carburetor-intake air, temperature above that of free air, °F							
					48	5	3
Temperature above that of free air, °F							
	Barrel, F	4	Front	Right	260	280	310
	Spark plug,F	4	----do---	---do----	360	395	440
	Spark plug,R	4	----do---	---do----	395	385	430
	Barrel, R	4	----do---	---do----	266		
	Barrel, F	5	Rear	---do----	250	265	295
	Spark plug,F	5	----do---	---do----	365	340	375
	Spark plug,R	5	----do---	---do----	405	395	430
	Barrel, R	5	----do---	---do----	305	240	270
	Barrel, F	11	----do---	Left	---	---	---
	Spark plug,F	11	----do---	---do----	340	335	370
	Spark plug,R	11	----do---	---do----	390	365	410
	Barrel, R	11	----do---	---do----	---	---	---
	Barrel, F	12	Front	---do----	235	290	315
	Spark plug,F	12	----do---	---do----	310	370	410
	Spark plug,R	12	----do---	---do----	360	365	405
	Barrel, R	12	----do---	---do----	320	230	260

[a]Cowl flaps fully closed.

TABLE III. - PERFORMANCE IN FULL-THROTTLE LEVEL RUNS WITH VARIOUS COOLING-SYSTEM ARRANGEMENTS ON A-17A AIRPLANE

	Free-air temperature (°F)	Density altitude (ft)	Observed		Adjusted to 10,000 ft	
			Air speed, V (mph)	Engine speed, N_e (rpm)	Air speed, V (mph)	Engine speed, N_e (rpm)
NACA cowling; flaps closed; exit-slot width, 2 in.	31	7,100	193.0	2270	188.4	2230
	8	9,000	192.3	2260	190.4	2250
	37	9,000	203.0	2350	201.1	2340
	59	10,300	206.0	2380	206.5	2390
	59	10,300	203.6	2370	204.1	2370
	59	10,300	203.2	2360	203.7	2360
	56	10,100	202.9	2360	203.0	2360
	56	10,100	202.9	2360	203.0	2360
	56	10,100	203.1	2360	203.2	2360
	56	10,100	202.7	2360	202.8	2360
Wing-duct system; exit-slot width, 2.7 in.	26	9,900	209.2	2400	209.0	2400
	26	9,950	212.2	2410	212.1	2410
	26	9,950	212.0	2410	211.9	2410
	26	9,900	208.3	2395	208.1	2395
	25	9,800	209.7	2400	209.3	2400
	25	9,850	208.8	2395	208.5	2395
	25	9,800	210.2	2425	209.8	2425
	50	9,850	210.7	2435	210.4	2435
	51	9,950	211.8	2435	211.6	2435
	52	9,950	212.0	2430	211.9	2430
	52	9,100	211.7	2435	210.2	2425
	52	9,100	210.0	2430	208.6	2420
	50	9,850	212.0	2440	211.7	2440
Wing-duct system; exit-slot width, 1.3 in.	26	9,900	212.7	2415	212.5	2415
	26	9,900	212.0	2410	211.8	2410
	26	9,950	211.1	2400	211.0	2400
	7	9,950	212.9	2415	212.8	2415
	7	9,900	211.8	2400	211.6	2400
	7	9,900	212.0	2385	211.8	2385
	9	10,000	212.0	2400	212.0	2400
	26	9,900	214.2	2430	214.0	2430
	25	9,850	215.1	2430	214.8	2430
	26	9,900	213.1	2430	212.9	2430
	25	9,900	217.4	2450	217.2	2450
	50	9,900	213.0	2435	212.8	2435
	51	9,950	213.4	2435	213.3	2435
	51	10,000	214.1	2435	214.1	2435
	53	9,150	212.3	2440	210.8	2435
	49	9,800	216.4	2465	216.0	2465

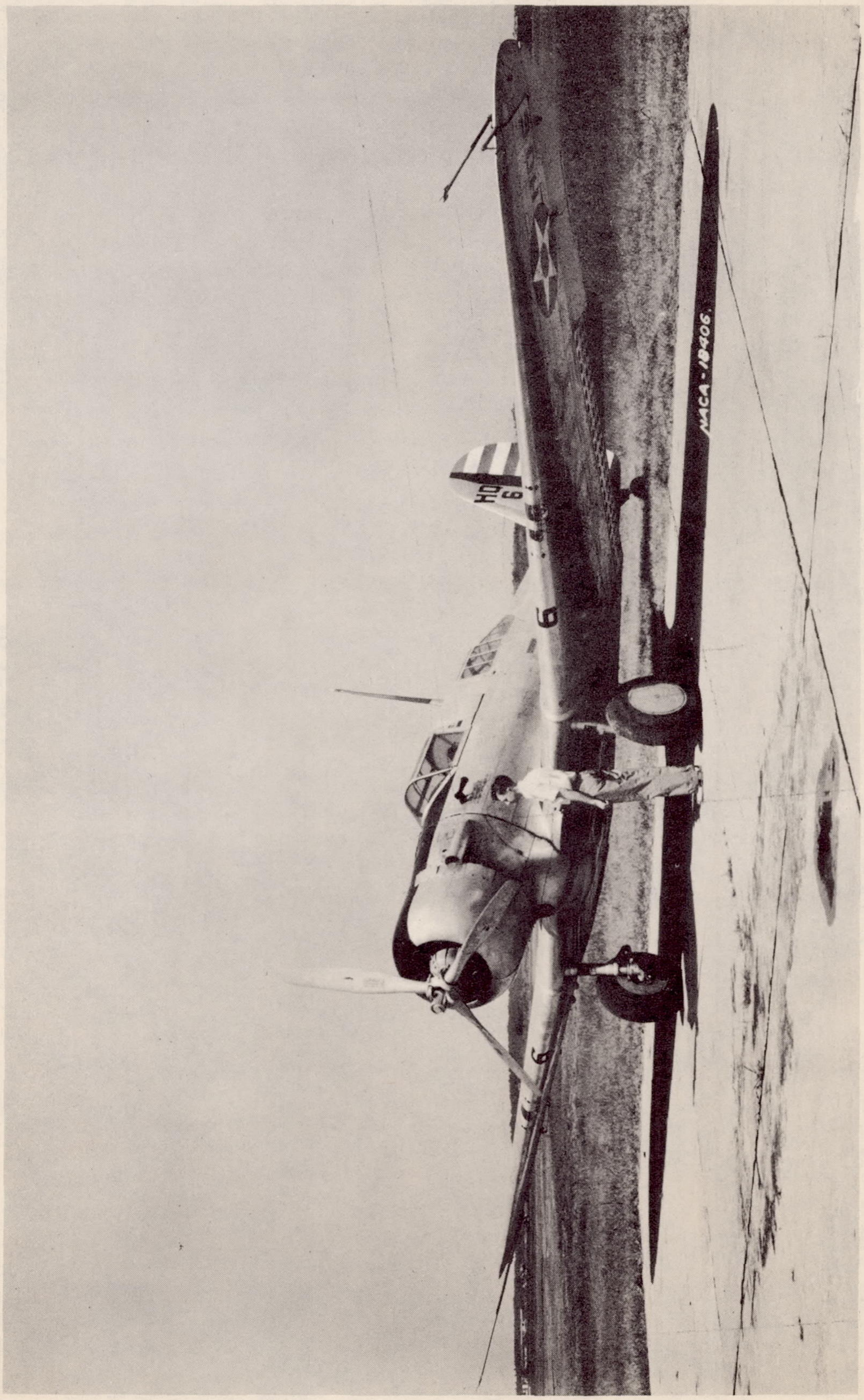

Figure 1.- One-quarter view of A-17A airplane with NACA cowling.

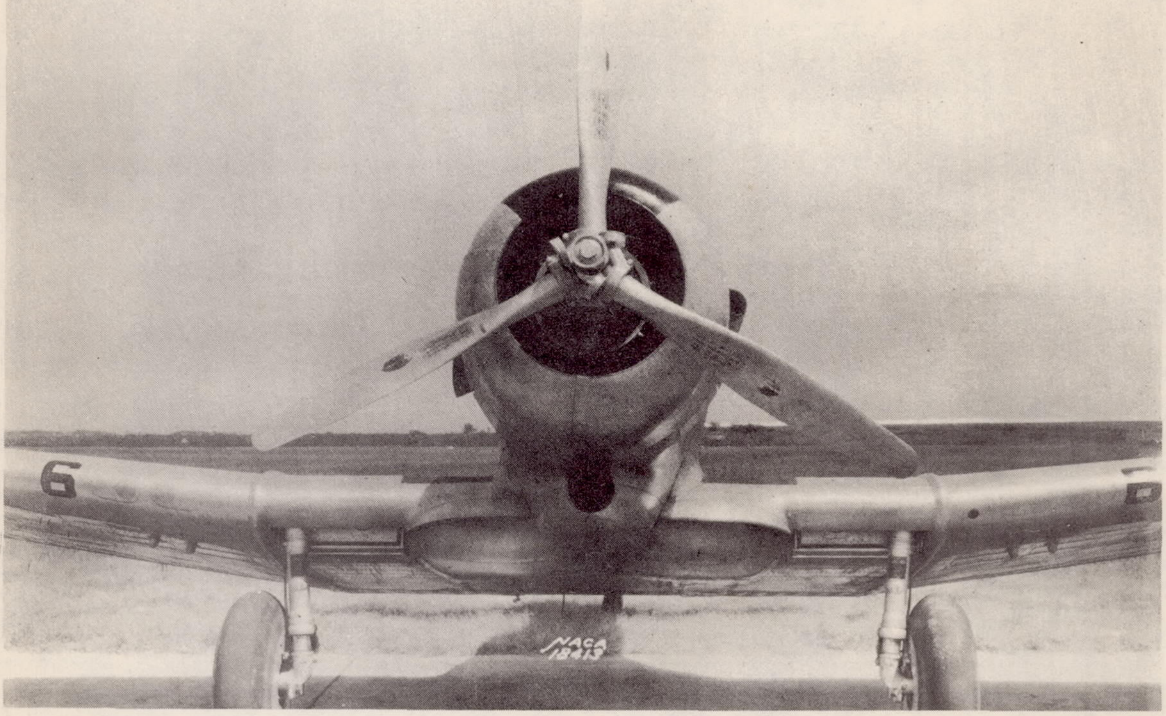

Figure 2.- Front view of NACA cowling on A-17A airplane.

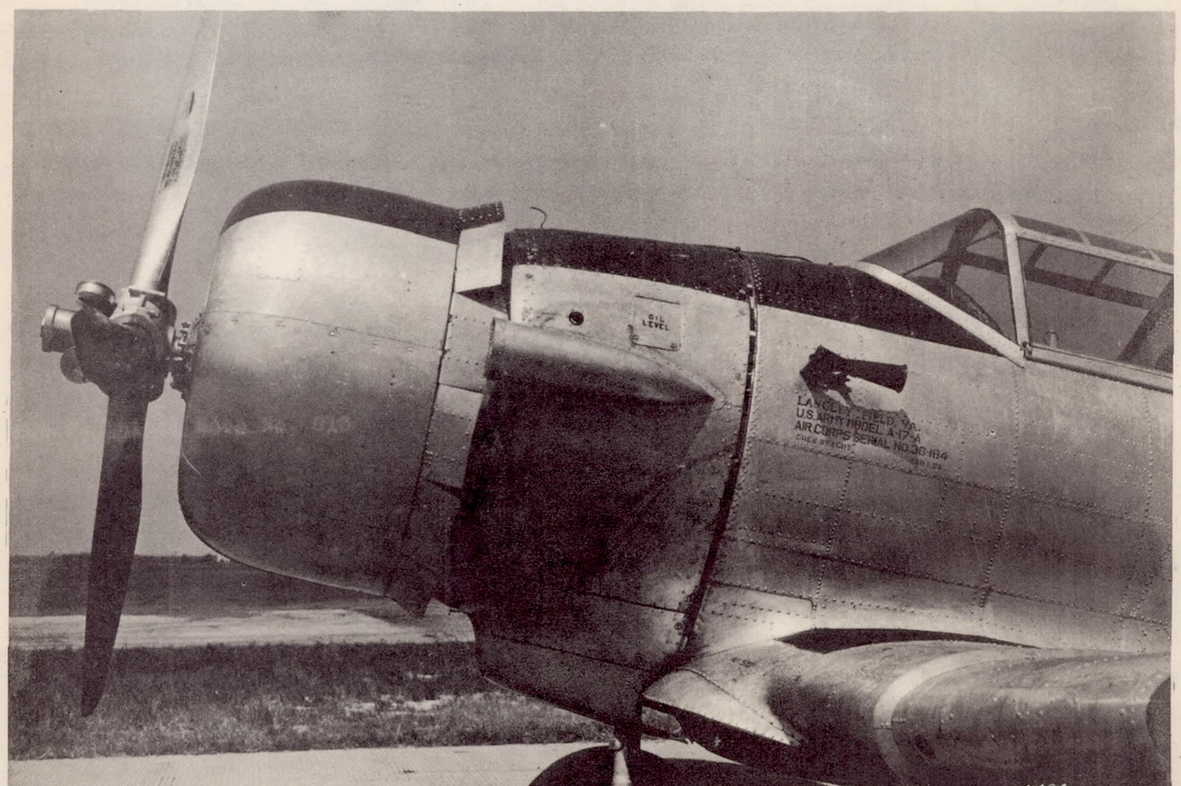

Figure 3.- Side view of NACA cowling with cowl flaps open on A-17A airplane.

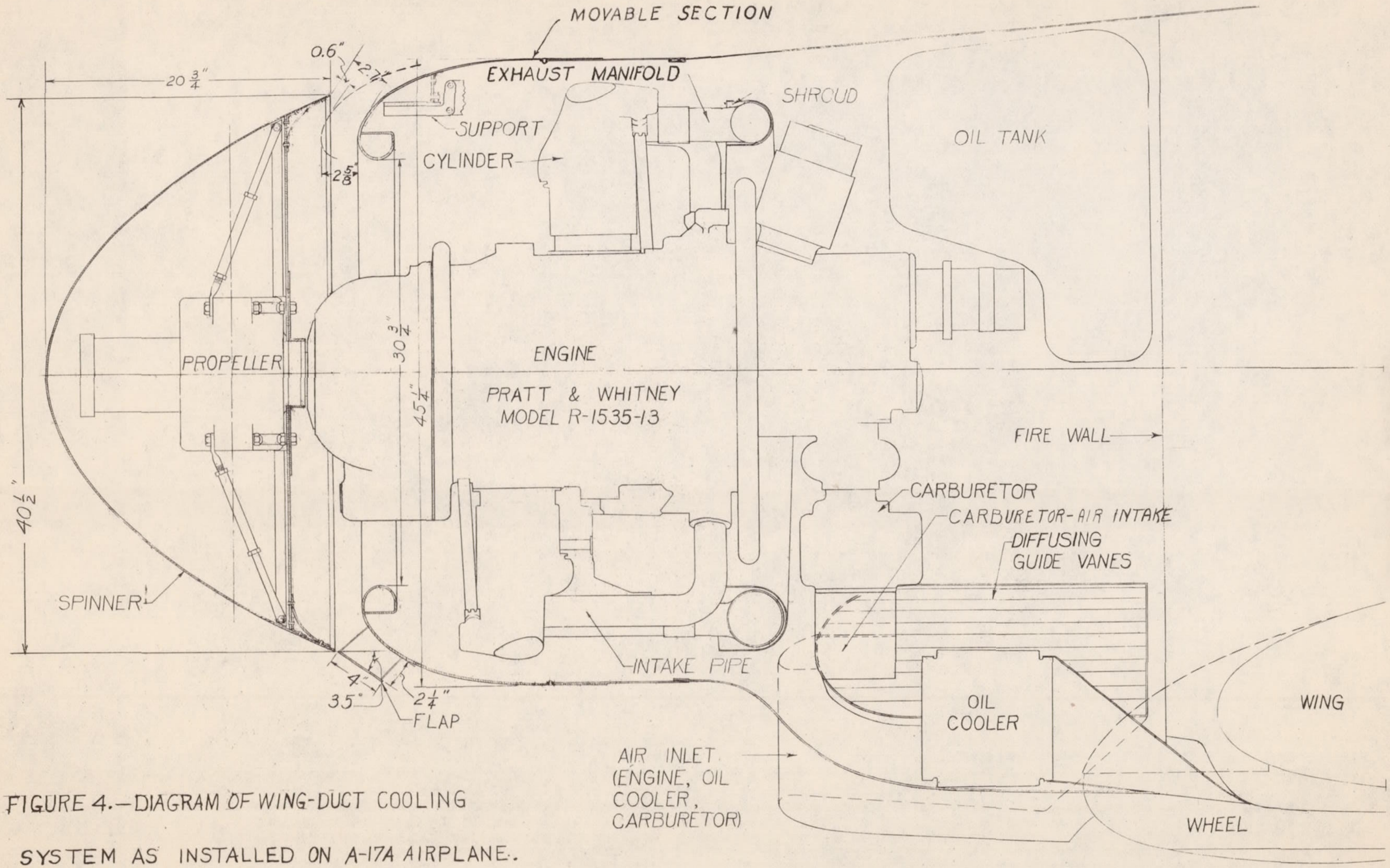

FIGURE 4.—DIAGRAM OF WING-DUCT COOLING SYSTEM AS INSTALLED ON A-17A AIRPLANE.

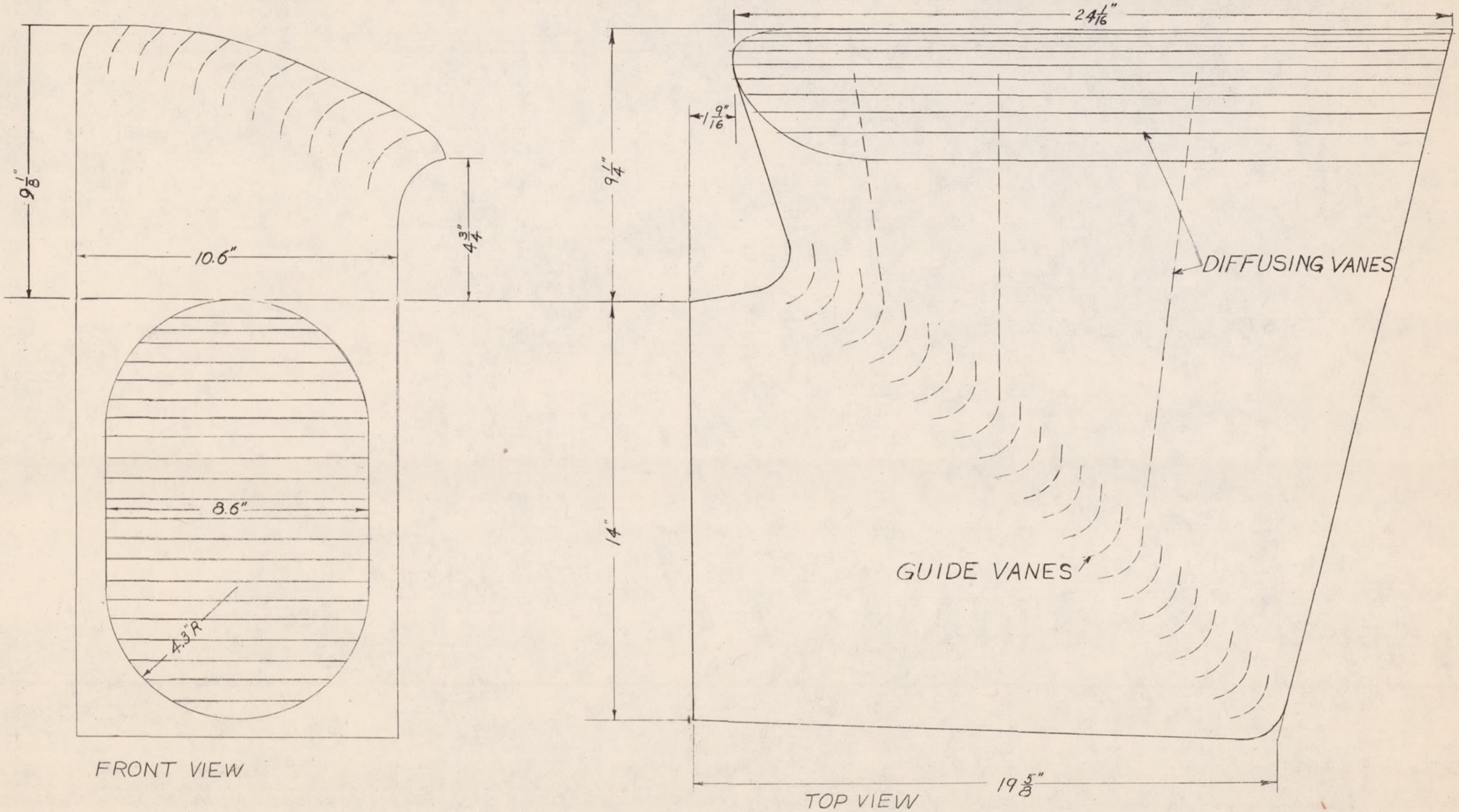

FIGURE 5.- DIAGRAM OF ENTRANCE DUCTS OF WING-DUCT COOLING SYSTEM AS INSTALLED ON A-17A AIRPLANE.

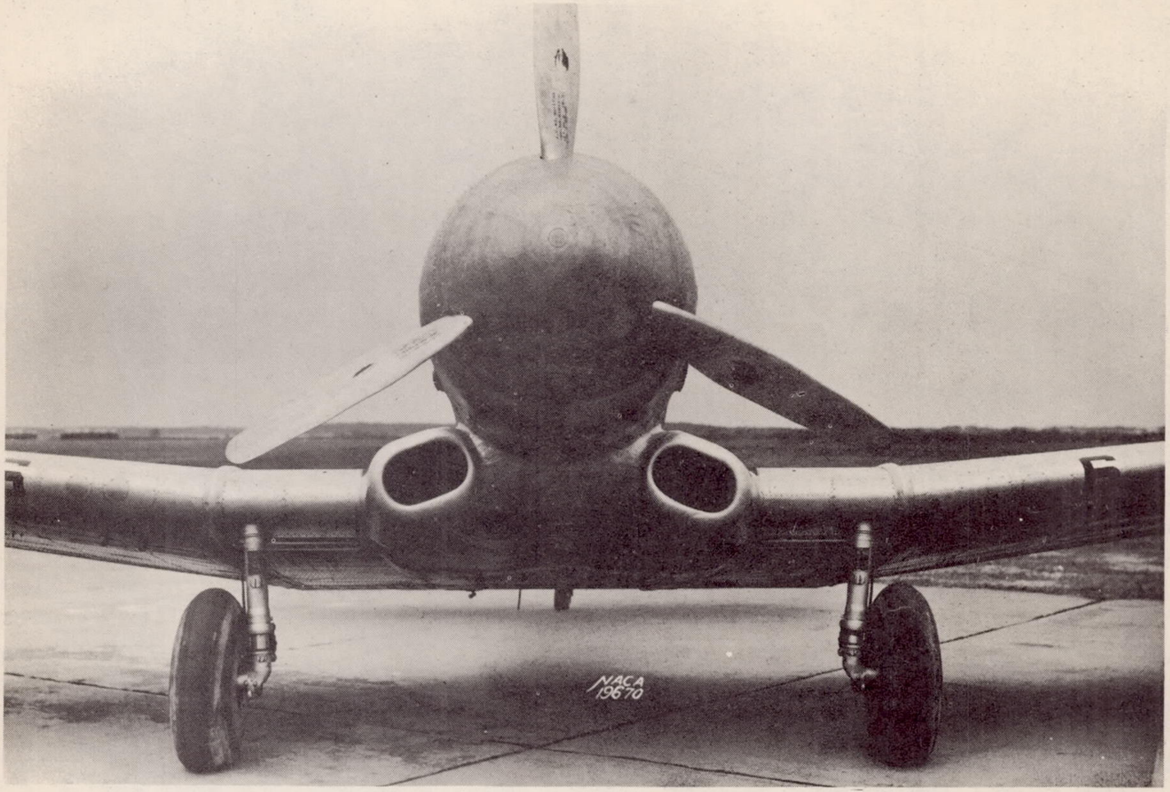

Figure 6.- Front view of wing-duct cooling system on A-17A airplane.

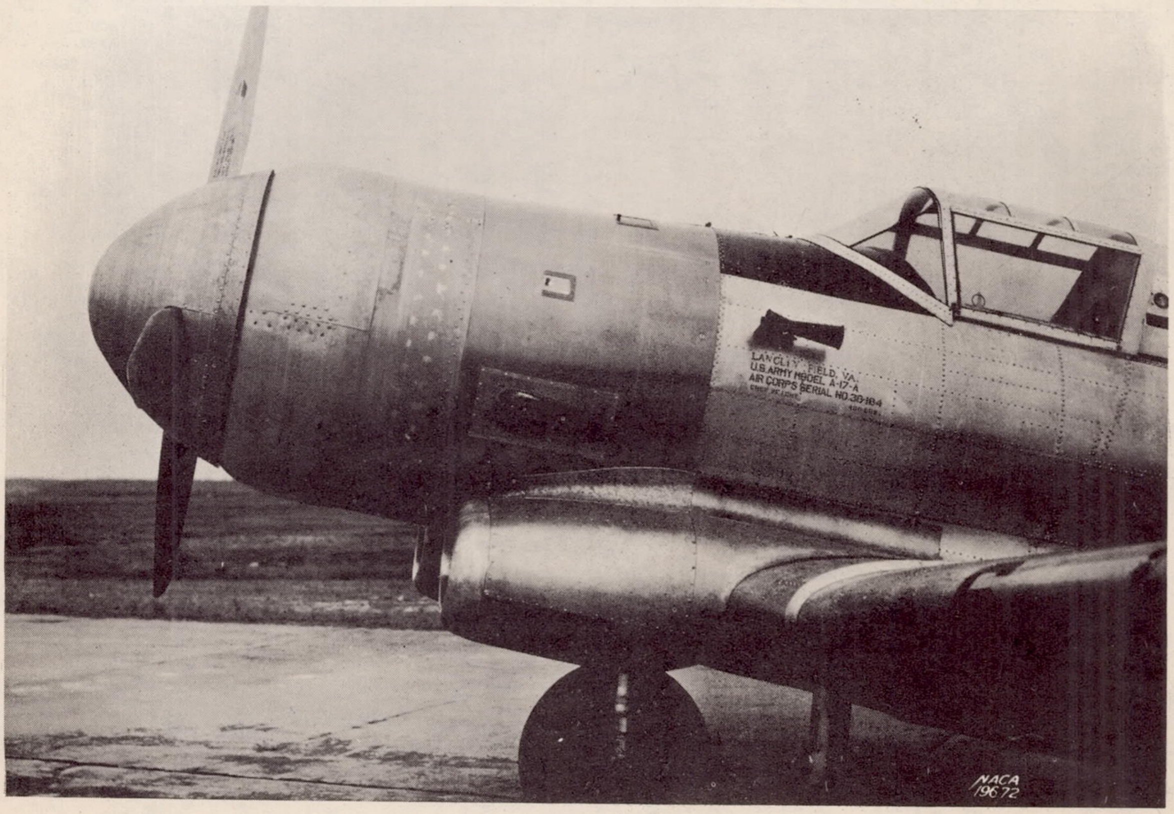

Figure 7.- Side view of wing-duct cooling system on A-17A airplane; exit-slot width, 0.6 inch.

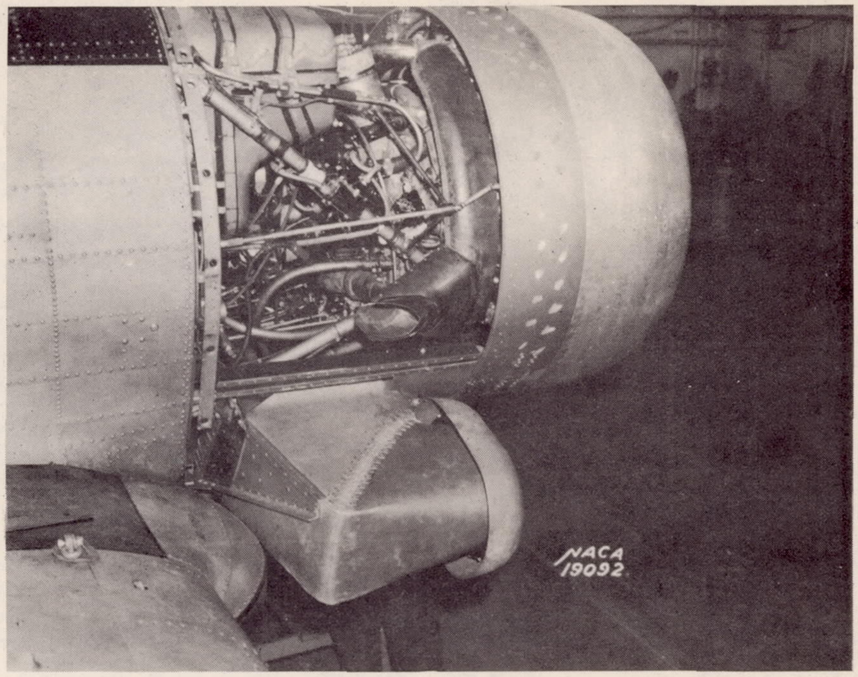

Figure 8.- Installation of wing-duct cooling system; the accessory compartment, the right exhaust cutlet and shrouding, and the right duct, before being faired.

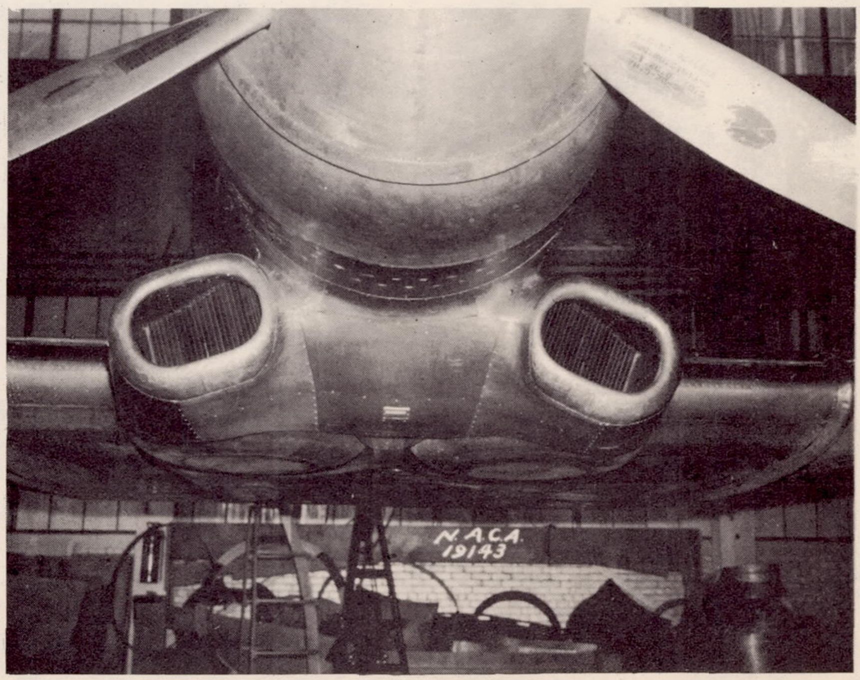

Figure 9.- Complete installation of ducts on A-17A airplane with wheels retracted.

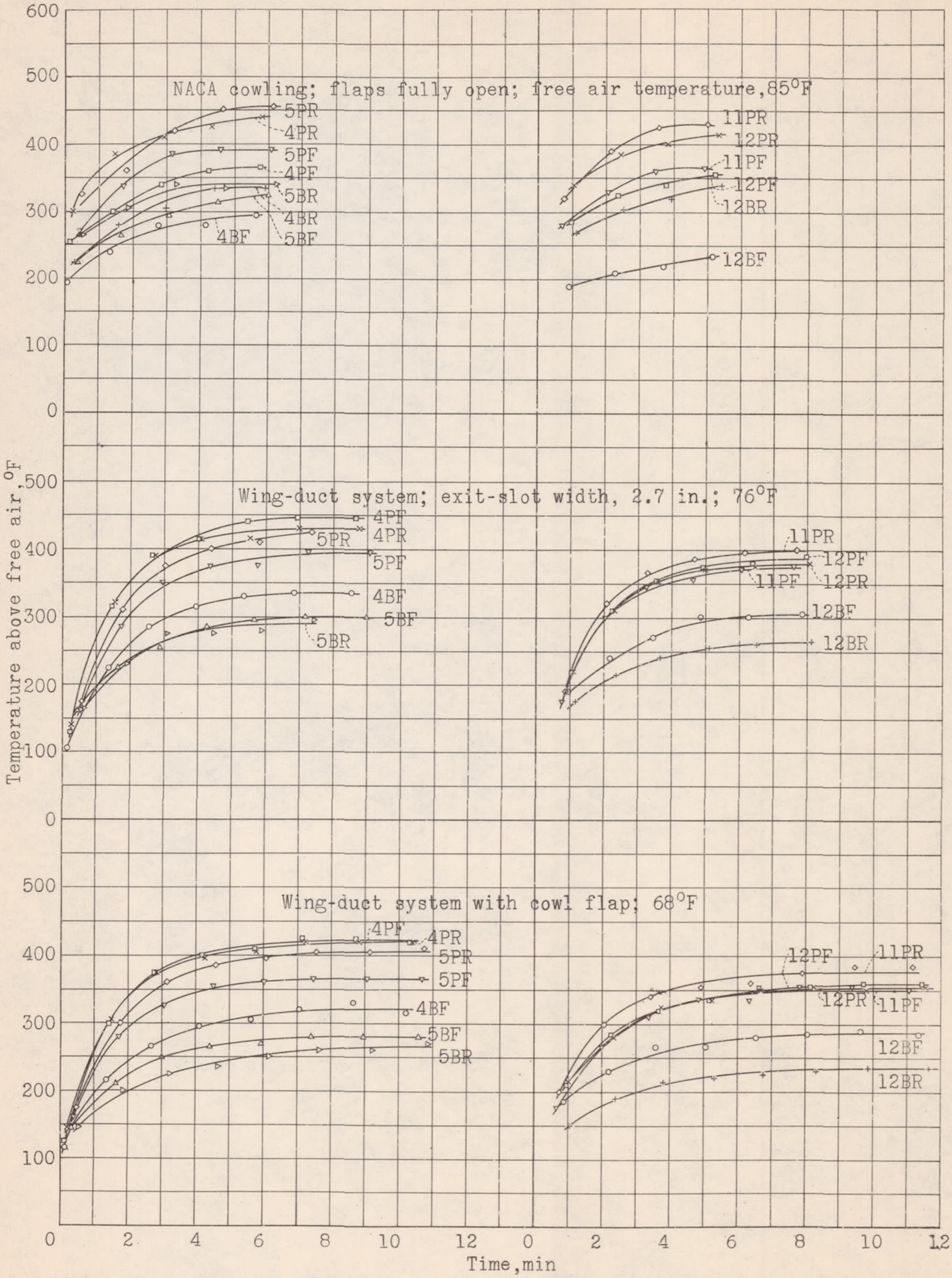

Figure 10.- Time histories of engine-cylinder temperatures for full-throttle ground operation of various cooling-system arrangements on A-17A airplane. Curve numbers correspond to cylinder numbers. P indicates plug; B, barrel; F, front of cylinder; R, rear of cylinder.

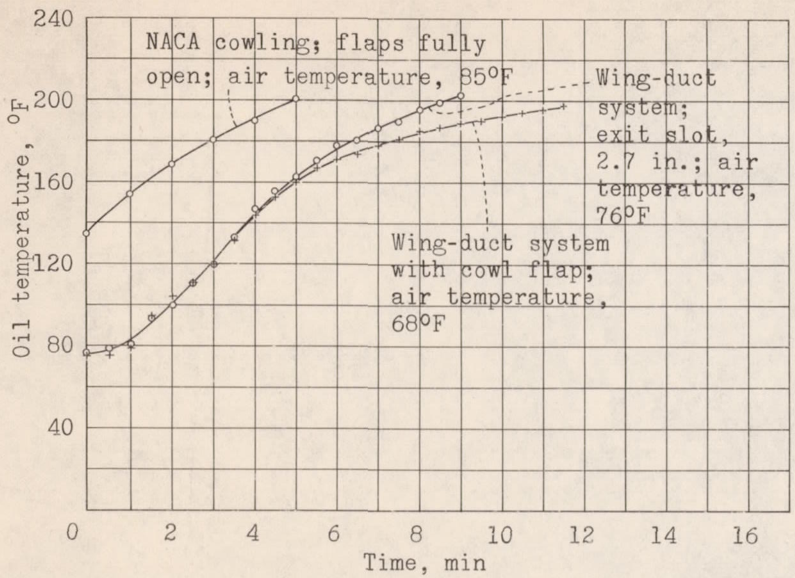

Figure 11.- Time histories of temperature of oil entering engine for full-throttle ground operation of various cooling-system arrangements on A-17A airplane.

Figure 12.- Pressure coefficients for wing-duct cooling system and NACA cowling on A-17A airplane. Δp_e, cooling-air pressure drop across engine; Δp_T, cooling-air pressure drop across duct and engine (exclusive of any loss at duct entrance); p_e, pressure inside mouth of duct relative to free-stream static. Propeller at high blade-angle setting except for V/nD = 0.