REPORT No. 596

COOLING TESTS OF A SINGLE-ROW RADIAL ENGINE WITH SEVERAL N. A. C. A. COWLINGS

By M. J. Brevoort, George W. Stickle, and Herman H. Ellerbrock, Jr.

SUMMARY

The cooling of a single-row radial air-cooled engine using several cowling arrangements has been studied in the N. A. C. A. 20-foot wind tunnel. The results show the effect of the propeller and several cowling arrangements on cooling for various values of the indicated horsepower in the climb condition. A table giving comparative performance of the various cowling arrangements is presented. The dependence of temperature on indicated horsepower and pressure drop across the baffles is shown by charts. Other charts show the limiting indicated horsepower against the pressure drop across the engine and the heat dissipated at various values of the indicated horsepower.

INTRODUCTION

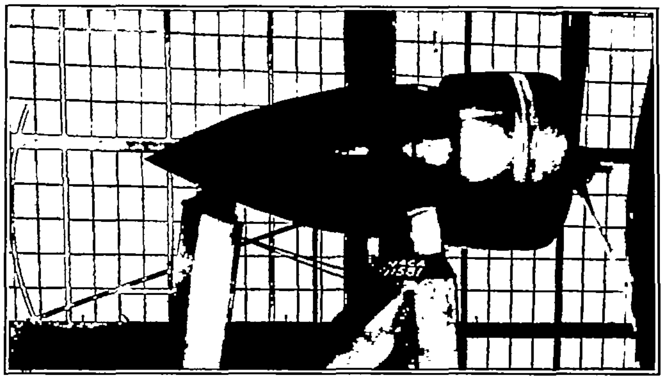
A study was made to determine the cooling characteristics and performance of a typical radial air-cooled engine, using several cowling arrangements. The tests were made in the N. A. C. A. 20-foot wind tunnel, which has a maximum speed of 110 miles per hour. With such a maximum speed the tests are obviously confined to the condition of climb. From practical considerations such a range is ideal because, except under very special operating conditions, the problem of cooling is most important during climb. It follows, then, that all conclusions concerning aerodynamic characteristics and efficiency drawn from these tests relate to the condition of climb alone. In tests covering the complete range of take-off, climb, and cruising conditions for several cowlings (references 1 and 2), it was shown that certain cowlings which appear aerodynamically good in climb are poor in the cruising condition.

The results show, for a particular engine, the relationship existing between the cooling and the developed horsepower and the pressure drop across the baffles. It is obvious that the results are, in detail, applicable only to this engine. In the discussion of the results, however, the chief emphasis is laid on general considerations and on the mechanism of cooling. It is believed that, although the details are interesting, the more important aspect of the investigation is the contribution to a clearer picture of the mechanism of cooling.

EQUIPMENT AND TESTS

The engine was mounted in the N. A. C. A. 20-foot wind tunnel (reference 3) as shown in figure 1. The engine is a 9-cylinder radial R-1340 S1H1-G Pratt & Whitney Wasp. The over-all diameter is 51$\frac{7}{16}$ inches. It is rated at 550 horsepower at 2,200 r. p. m. and at 8,000 feet altitude. It has a 3:2 reduction gear, a compression ratio of 6, and is equipped with a geared centrifugal supercharger that operates at 12 times engine speed. The bore of the cylinders is 5.75 inches and the stroke is 5.75 inches.

(a) Bare engine.

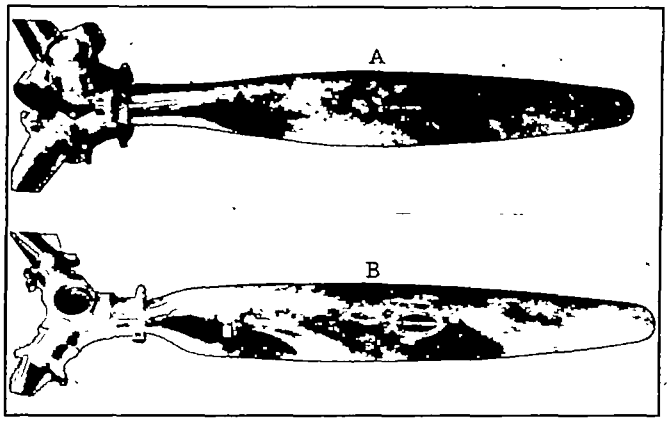


(b) With cowling.

FIGURE 1.—Engine and nacelle set-ups.

The two propellers used are shown in figure 2. Propeller A is a Hamilton Standard controllable propeller of blade form No. 6101-0 and propeller B is a Hamilton Standard adjustable propeller of blade form No. 1C1-0.

Figure 3 is a profile drawing of the engine and nacelle with the various noses, skirts, and inner cowlings used in this study.



Controllable (A). Adjustable (B).

FIGURE 2.—Propellers used.

Figure 4 shows the arrangement of baffles on the head and barrel of the cylinder. Note that these baffles are not tightly fitting in the sense that they touch the fin tips but that they are comparatively close-fitting baffles.

The temperature of the engine was measured by 24 thermocouples connected to a recording pyrometer. The thermocouples were peened to the head and spot-welded to the barrel of the cylinder. The thermocouple locations on cylinder 3 are shown by figure 5. Thermocouples 1 to 9 were located on cylinders 1 to 9, respectively, at the position indicated for thermocouple 3 in figure 5. Thermocouples 10, 11, 12, and 13 were located on cylinders 1, 3, 5, and 7 at the position shown for thermocouple 11. Thermocouple 24 was located on cylinder 8 at the position of thermocouple 23 on cylinder 3. The remaining thermocouples were located on cylinder 3. Cylinders are numbered counterclockwise, cylinder 1 being at the top.

Air temperatures in front of and behind the engine, oil-in and oil-out temperatures, and carburetor-air temperatures were measured by shielded resistance thermometers. The oil was cooled by a water radiator located inside the nacelle.

The drop in pressure across the engine was measured by pitot-static tubes located in front of and behind the cylinders. The quantity of air passing through the baffles was measured by pitot-static tubes located in the skirt exit.

The engine power was controlled by varying the manifold pressure. The manifold pressure, engine speed, and air temperature gave the horsepower from a calibration furnished by the manufacturer. The fuel consumption was measured and frequent checks were made on the exhaust-gas analysis from each cylinder.

The routine of an individual test was as follows: The engine speed, the horsepower, and the tunnel speed were adjusted to the desired values. Sufficient time was allowed for all temperatures to become stabilized. All temperatures and pressures were then recorded. This procedure was repeated for various values of engine speed, indicated horsepower, and tunnel speed. Each cowling arrangment was tested in this manner. Ranges of engine speeds from 1,600 to 2,000 r. p. m., power from 300 to 550 horsepower, and air speeds from 80 to 110 miles per hour were covered. Drag tests with propeller off were made.

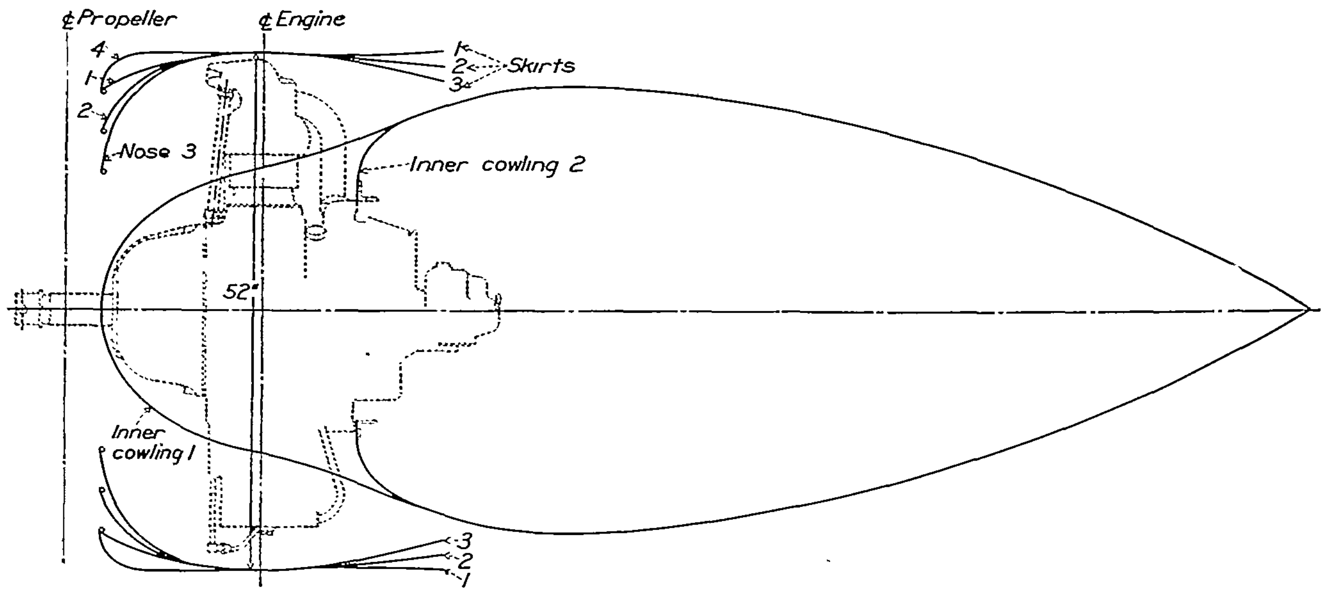


FIGURE 3.—Sketch of cowlings tested. Wasp S1H1-G engine fairing and cowlings.

LIST OF SYMBOLS

Q, quantity of cooling air passing through the engine per second.

Δp, pressure drop across the baffle.

$K=\dfrac{\frac{A}{F}}{\sqrt{\frac{\Delta p}{q}}}$, conductivity of the engine.

F, cross-sectional area of the engine.
ρ, mass density of the air.
A, area of the free air stream entering the engine.

$q=\frac{1}{2}\rho V^2$, dynamic pressure of the free air stream.

p_f, pressure in front of the cylinder.
p_r, pressure in rear of the cylinder.
V, velocity of the free air stream.

$P_c=\dfrac{P}{qSV}$, propeller disk loading coefficient.

P, power supplied to the propeller.
S, disk area of the propeller.
n, revolutions per second of the propeller.
D, diameter of the propeller.
ΔT, difference between the temperature of a particular point on the cylinder and that of the inlet cooling air.

ANALYSIS OF THE PROBLEM

The useful work done in cooling the engine is $Q\Delta p$, and Q is proportional to $\sqrt{\Delta p}$. The power to cool can then be written as proportional to $(\Delta p)^{3/2}$. It has been shown in reference 1 that

$$\text{Power to cool}=\frac{\sqrt{2}KF(\Delta p)^{3/2}}{\sqrt{\rho}}$$

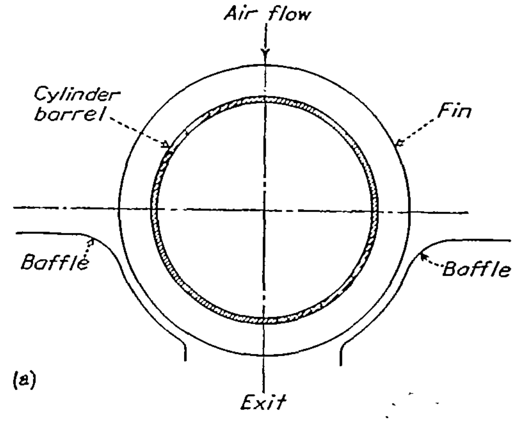
$$K=\frac{\frac{A}{F}}{\sqrt{\frac{\Delta p}{q}}}$$

The value $K=0.06$ was constant throughout the investigation. It depends entirely upon the finning and the baffling of the cylinders. The pressure drop Δp is a function of the air-stream velocity and of the cowling and baffle design. It is obvious from the foregoing equation that the selection of the minimum values of K and Δp which will provide adequate cooling is very desirable from the standpoint of aerodynamic efficiency.

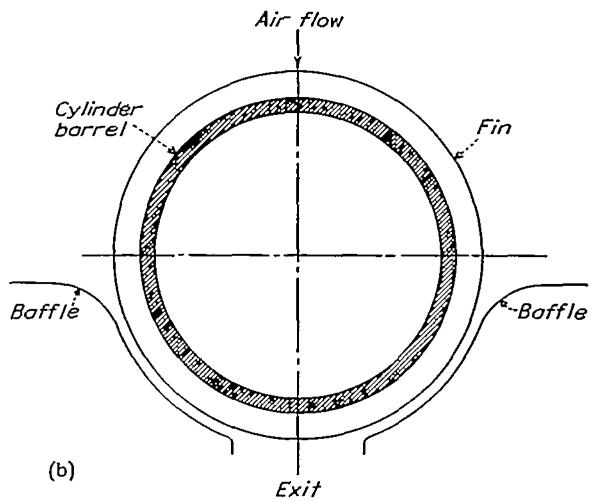
Reference 1 has shown that it is practically impossible to develop a Δp of more than $1.3q$ for this general type of cowling. Such a high value, moreover, is attained at very low efficiency.

The problem, then, is to determine under what conditions and how efficiently the modern engine can be cooled with various pressure drops. This study of the climb condition answers a part of that question.

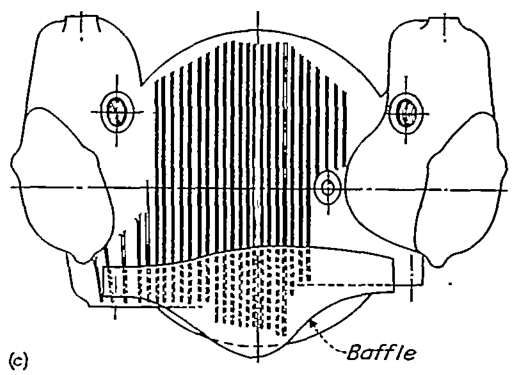
In such a study it is extremely important that only the quantity under consideration be permitted to vary, all other factors remaining constant. This condition is particularly difficult when the tests are made on an actual engine, where variations in air-fuel ratio, carburetor-air temperature, oil temperature, oil pressure-



(a) Barrel.



(b) Lower head.



(c) Head.

FIGURE 4.—Baffle arrangement.

and mechanical condition of the engine must be eliminated as far as possible. Tests have shown (reference 4) that a variation of 1.0 in the air-fuel ratio will result in a change of approximately 20° F. in the cylinder temperature. The maximum variation from cylinder to cylinder was 0.8 of a ratio, which should result in a temperature variation of 16° F. The carburetor-air temperature never varied more than 24° F. for a single cowling test nor more than 58° F. for all the tests. Such variations will, according to unpublished test results, cause temperature variations of 3° F. and 8° F., respectively. The oil temperature and pressure were maintained relatively constant and the spark plugs and mechanical condition of the engine were checked at frequent intervals.

It is believed that the careful control of these variables reduced the variation in results due to undesired causes to a minimum. The air-fuel ratio was checked by exhaust-gas analysis and the fuel consumption was maintained constant at 0.57 lb./b. hp.-hr. by the use of a fuel flow meter. The variations of air-fuel ratio from cylinder to cylinder are characteristic of the engine and check the cylinder-to-cylinder temperature variation reasonably well. Any variation due to carburetor-air temperature or over-all air-fuel ratio affects all cylinders and causes discrepancies resulting in a scattering of the points. This type of variation was relatively small.

Isolated cases of temperatures that appear to be in error by as much as 40° F. will be found but, in general, the temperatures are accurate to ±10° F.

RESULTS

Table 1 is presented as a short résumé of the results for all the cowlings for a particular horsepower, engine speed, and air speed. Column 1 gives the number of the nose; column 2 gives the number of the skirt; column 3 gives the number of the inner cowling. These three numbers are used, in the same order, to designate the complete cowling. Column 4 gives the measured drag of the engine and nacelle at a dynamic pressure of 25.6 pounds per square foot. Column 5 gives the propeller designation. Column 6 gives the pressure in front of the cylinders divided by the dynamic pressure; column 7 gives the pressure in rear of the cylinders divided by the dynamic pressure; column 8 is the difference between columns 6 and 7, or the pressure drop, in percentage of q, across the baffles. Column 9 is the actual pressure drop across the baffles in pounds per square foot at a dynamic pressure of 25.6 pounds per square foot, which corresponds to 100 miles per hour under standard conditions. Column 10 gives the temperature in front of the cylinder, an average of thermocouples 10 through 13; column 11 gives the temperature in the rear of the cylinder, an average of thermocouples 1 through 9. Throughout the report, all temperatures are given as the difference between the temperature at

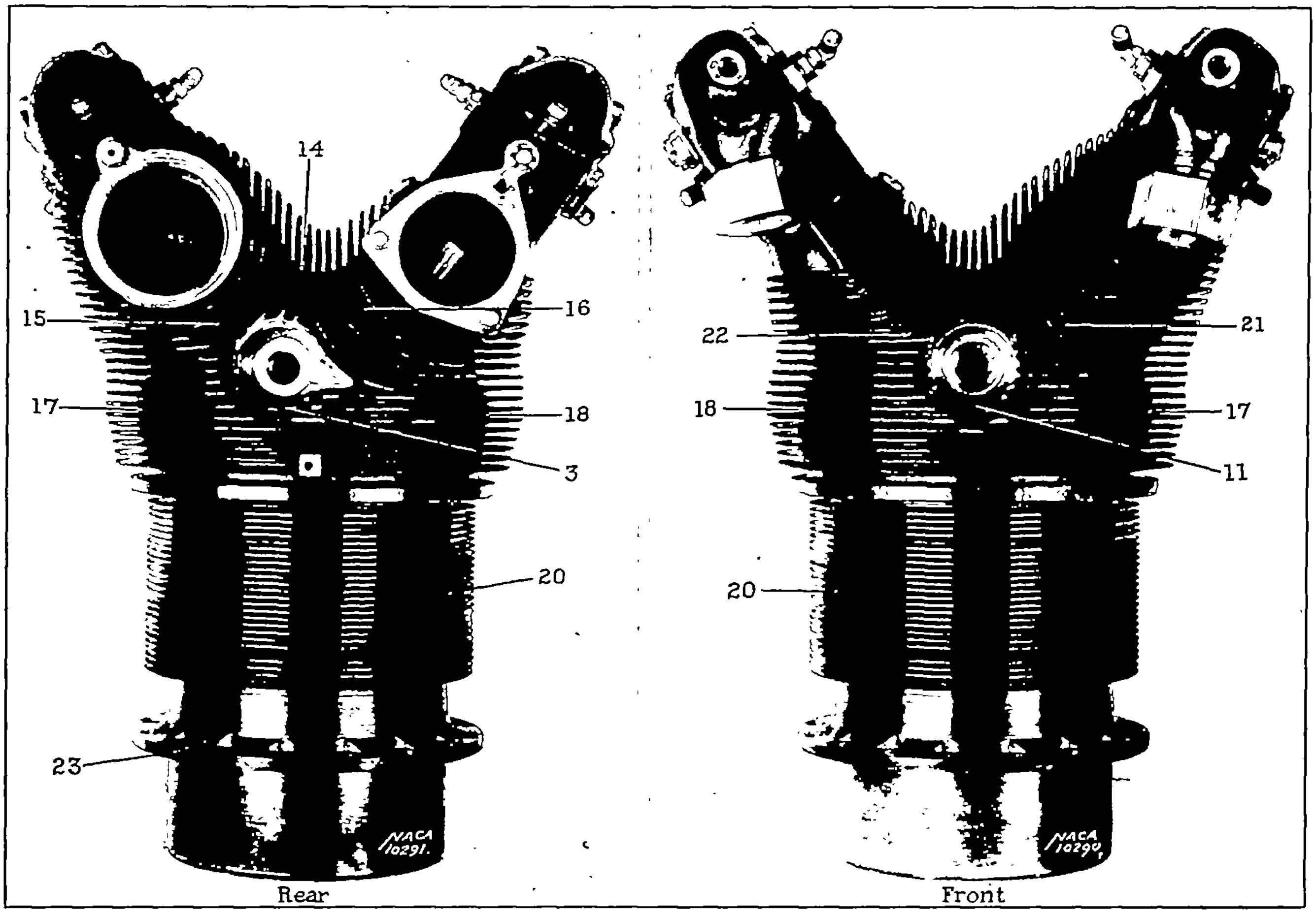


FIGURE 5.—Thermocouple locations on cylinder 3.

a particular point on the cylinder and that of the inlet cooling air. Column 12 gives the net thrust of the engine-propeller-nacelle unit at a value of $1/\sqrt[3]{P_c}=1.12$ and a velocity of 100 miles per hour.

TABLE I

[100 m. p. h.; 425 i. hp.; 1,800 r. p. m.; 380 b. hp.]

1	2	3	4	5	6	7	8	9	10	11	12
									Temperature difference		
Nose	Skirt	Inner cowling	Drag (lb.) at q=25.6 lb. per sq. ft.	Propeller	$\frac{p_f}{q}$	$\frac{p_r}{q}$	$\frac{\Delta p}{q}$	Δp (lb. per sq. ft.)	Front (°F.)	Rear (°F.)	Net thrust (lb.) for $1/\sqrt[3]{P_c}$ = 1.12 and q=25.6 lb. per sq. ft.
1	1	1	152.4	Off	1.00	−0.252	1.252	32.0			
1	1	1		A	0.782	−.508	1.290	32.1	273	239	931
1	2	1	117.1	Off	.990	−.091	1.081	27.7			
1	2	1		A	.770	−.083	.853	21.1	293	279	963
1	3	1	106.8	Off	.975	.091	.884	22.6			
1	3	1		A	.849	.227	.622	15.2	292	296	979
2	3	1	53.5	Off	.977	.159	.818	21.3			
2	3	1		A	.824	.271	.553	13.7	275	313	950
2	2	1	69.0	Off	.978	−.068	1.046	26.5			
2	2	1		A	.752	−.114	.866	21.0	265	291	925
2	1	1	110.9	Off	.972	−.280	1.252	31.4			
2	1	1		A	.725	−.512	1.237	29.7	265	267	897
3	1	1	110.5	Off	.868	−.299	1.167	29.8			
3	1	1		A	.560	−.514	1.074	26.0	257	275	916
3	2	1	68.0	Off	.903	−.099	1.002	25.7			
3	2	1		A	.628	−.137	.765	18.8	286	309	942
3	3	1	55.2	Off	.920	.141	.779	20.3			
3	3	1		A	.671	.186	.485	11.8	315	357	937
4	3	1	56.0	Off	.984	.162	.822	21.4			
4	3	1		A	.808	.247	.561	13.7	304	320	947
4	1	1	111.0	Off	1.000	−.273	1.273	32.1			
4	1	1		A	.852	−.519	1.371	32.9	274	268	875
3	1	2	121.5	Off	.913	−.268	1.181	30.5			
3	1	2		A	.628	−.464	1.092	26.8	266	274	906
2	1	2	119.0	Off	.955	−.284	1.239	32.0			
2	1	2		A	.726	−.491	1.217	29.7	265	290	884
1	1	2	150.0	Off	.949	−.288	1.237	31.2			
1	1	2		A	.808	−.480	1.288	32.3	266	241	916
4	1	2	119.2	Off	.945	−.281	1.226	31.5			
4	1	2		A	.836	−.481	1.317	33.2	263	260	870
4	2	2	73.0	Off	.950	−.042	.992	25.5			
4	2	2		A	.810	−.042	.852	20.4	292	296	907

The dependence of the temperature upon the pressure drop is quite apparent. It can also be seen that large pressure drops are very costly in drag. It is evident that, for cases of propeller on, the pressure in front of the cylinder is decreased and that in the rear is exaggerated; that is, a negative pressure behind the cylinder with propeller off becomes more negative with propeller on and a positive pressure becomes more positive. It is well to remember that this effect of the slipstream is of importance only in the low-speed range; it becomes negligible under cruising conditions. Further, except in a few arrangements using skirt 1, which has a wide opening, $\Delta p/q$ is actually higher without the propeller operating. Another point of interest is that the maximum value of $\Delta p/q$ is approximately 1.3 in spite of the high power put into the slipstream.

The net thrust of the engine-propeller-nacelle unit as given in column 12 shows that nose 1 gives the greatest net thrust. It can be seen that this same nose gave the highest drag with the propeller off (column 4). This seemingly contradictory result is caused by the critical flow over the leading edge of nose 1 and is consistent with the results of references 1 and 2. Attention is called to the fact that nose 1 is again inferior in the high-speed range (reference 1). This result brings out the importance of testing cowlings at the operating condition under which best operation is desired.

Table I introduces the type of result derived from the tests. The plan of presentation of the results will be to show by charts the interdependence of the various quantities as the engine power, the air speed, etc., are varied.

Figure 6 shows plots of $\sqrt{\Delta p}/n$ against V/nD for the 10-foot-diameter propeller used. Plots of this type conveniently picture the relationship between the available pressure, the air speed, and the propeller speed. These results are not directly comparable with those presented in reference 2. The present tests were made using a controllable propeller, the blade-angle setting varying throughout the range of V/nD; whereas the tests of references 1 and 2 were made using an adjustable propeller, the setting remaining constant throughout the range of V/nD. Figure 7 shows plots of $\sqrt{\Delta p}/n$ against V/nD for the various arrangements, with a dashed line showing the case of propeller off. Such a line is known to pass through the origin and to have a slope of $\sqrt{\Delta p}\,D/V$ so that it can be precisely drawn. It is of interest to show the little-realized fact that a propeller with a large hub and a round blade section near the hub often decreases instead of increasing the Δp obtained without the propeller. One exception is noted, the arrangement 4–1–1, shown in figure 7 (d). Propellers with a good airfoil section near the hub, such as propeller B in figure 7 (d), give an increase in Δp.

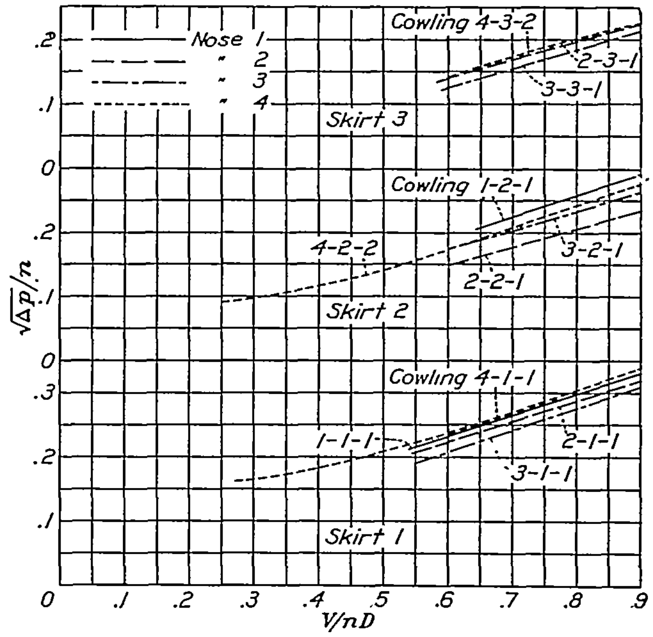


FIGURE 6.—Variation of the pressure constant $\sqrt{\Delta p}/n$ with V/nD and cowling arrangements.

Figure 8 shows the temperature difference plotted against the indicated horsepower. The points determining a given line are for a constant Δp. The scattering of the points can be explained by small variations in Δp. The conditions under which the tests were run are indicated. Although the range is not sufficient to define the slope precisely, lines drawn with a slope of 0.37 are quite consistent with the data. This result is all the more convincing when one considers that the points are taken for several engine speeds. Further, this slope is of the same magnitude as that found by Schey and Pinkel (reference 5) from flight tests on a Pratt & Whitney 1535 supercharged engine. It is recognized that this slope is a function of the baffling, the cylinder finning, and the mechanism of cooling; consequently, it can be used only for the arrangement tested. It is necessary, however, in studying cowling performance to be able to correct for variations in horsepower. The determination of such a slope makes this possible.

Cross plots (fig. 9) of the curves of figure 8, in which the indicated horsepower is plotted against Δp for three temperature differences, give three curves that show the limiting indicated horsepower permissible at various values of Δp. These curves show the advantage, with limited power, of allowing as high a cylinder temperature as possible.

The slope found in figure 8 is used in figure 10, in which the temperature difference divided by the indicated horsepower to the 0.37 power is plotted against

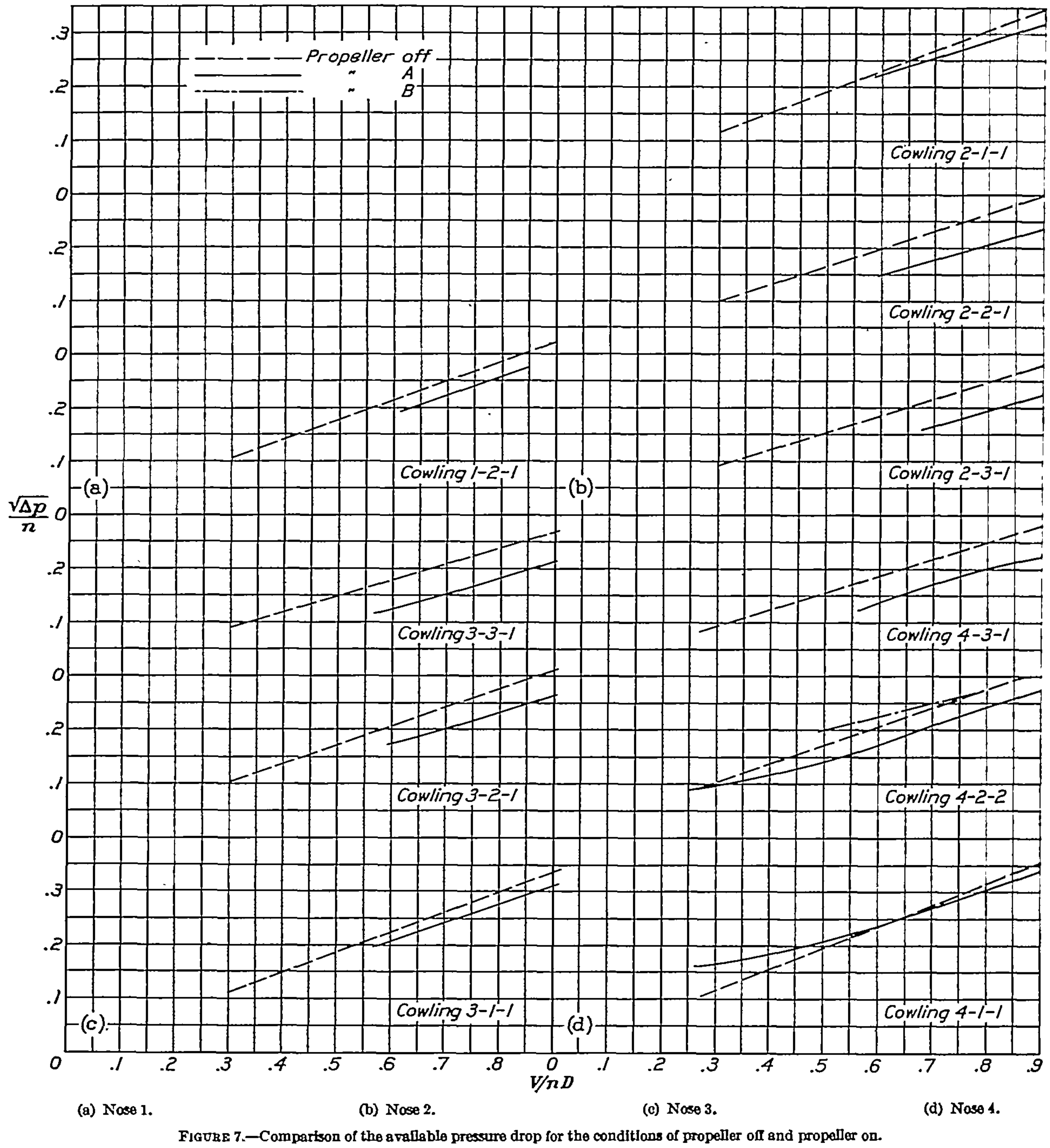


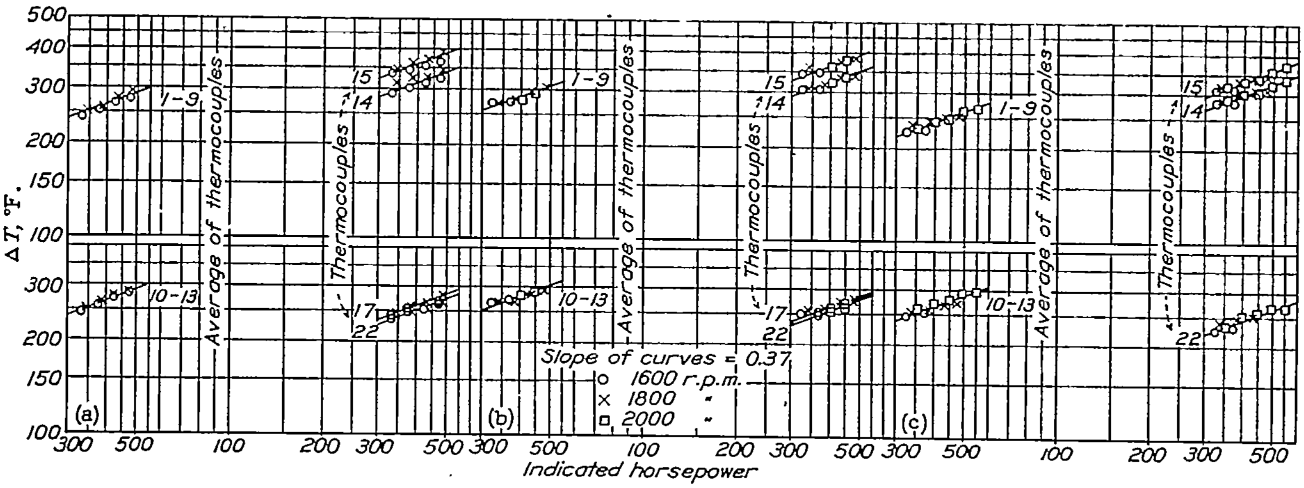
FIGURE 7.—Comparison of the available pressure drop for the conditions of propeller off and propeller on.

$2\Delta p$. The value $2\Delta p$ is used instead of Δp for convenience in plotting. These curves show reasonable slopes for the dependence of cooling on Δp. The slope may vary from -0.4 to 0, -0.4 resulting from a completely turbulent boundary layer on fins of narrow width. The minimum slope will result when the cooling does not depend upon the velocity flow. Intermediate values of the slope correspond to longer fins (reference 6) and laminar flow in the boundary layer. Thus, when part of the cooling is accomplished by other means than a directed velocity flow of air over the fins, the slope will be less than was expected. This result is particularly true of the front of the cylinder, where there is no directed velocity. The only reason for the existence of a slope is the fact that both turbulence and Δp are functions of the air-stream velocity. It has been shown (reference 1) that the cooling in the front of the cylinder is accomplished by such large-scale turbulence. The consistently lower slopes found for the thermocouples on the front than on the rear of the cylinder in this study confirm this result.

Figure 11 shows plots similar to those of figure 10 for noses 2, 3, and 4. Here again it is noted that the curves for the thermocouples on the front of the cylinder have lower slopes. The wide scattering of the points in some cases for the front thermocouples can possibly be explained as follows: Δp can be varied in two ways, by varying the air-stream velocity and, as a result, the turbulence, or by varying the skirt exit. When Δp is simultaneously varied by both means, it is quite likely to cause considerable scattering.

Figure 12 shows the dependence of ΔT on Δp for several positions on the cylinder at a constant horsepower. The results are shown for both the adjustable and the controllable propellers. The temperatures in the rear show the same dependence on Δp as in the previous charts. The temperatures on the front show a lack of dependence on Δp that cannot be explained.

It has been shown, in the analysis of the problem, that the power required to cool is $\frac{\sqrt{2}KF(\Delta)p^{3/2}}{\sqrt{\rho}}$. It has been calculated for the tests of cowlings 2, 3, and 4 and is shown in figure 13 plotted against the temperature difference. This chart serves to emphasize the well-known fact that a small reduction in temperature is accomplished at a large expenditure of power to cool. It becomes all the more striking when it is remembered that large expenditures of power are, in general, made at relatively low efficiencies. If it is assumed that a rea-



	Cowling	Approximate air speed, m. p. h.	Pressure drop across cylinder Δp, lb./sq. ft.
(a)	1-2-1	80	21.1
(b)	1-3-1	100	14.2
(c)	1-1-2	110	31.8

FIGURE 8.—The effect of indicated horsepower on the cylinder temperature difference. Fuel consumption, 0.57 pound per brake horsepower-hour.

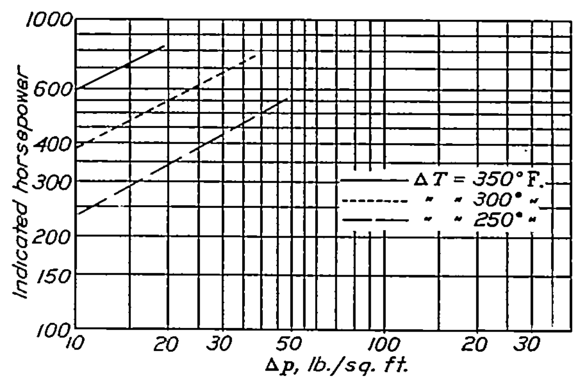


FIGURE 9.—The effect of Δp on the limiting horsepower at several constant temperature differences. Average of thermocouples 1 to 9.

sonable operating temperature involves a temperature difference of 300° F., then it is evident (fig. 13) that the cost in power to cool is from 1 to 1.5 percent of the indicated horsepower.

As a rule, the heat dissipated is not directly discussed in such an analysis. Measurements were made, however, that allow a rough determination of the heat dissipated both to the cooling air and to the oil cooler. Figure 14 shows the amount of heat dissipated to the cooling air for several arrangements, and figure 15 shows the amount dissipated to the oil cooler. The percentage of the indicated horsepower dissipated varies from 40 to 75. It will be noted that the percentage of heat dissipated is relatively higher at lower indicated horsepower.

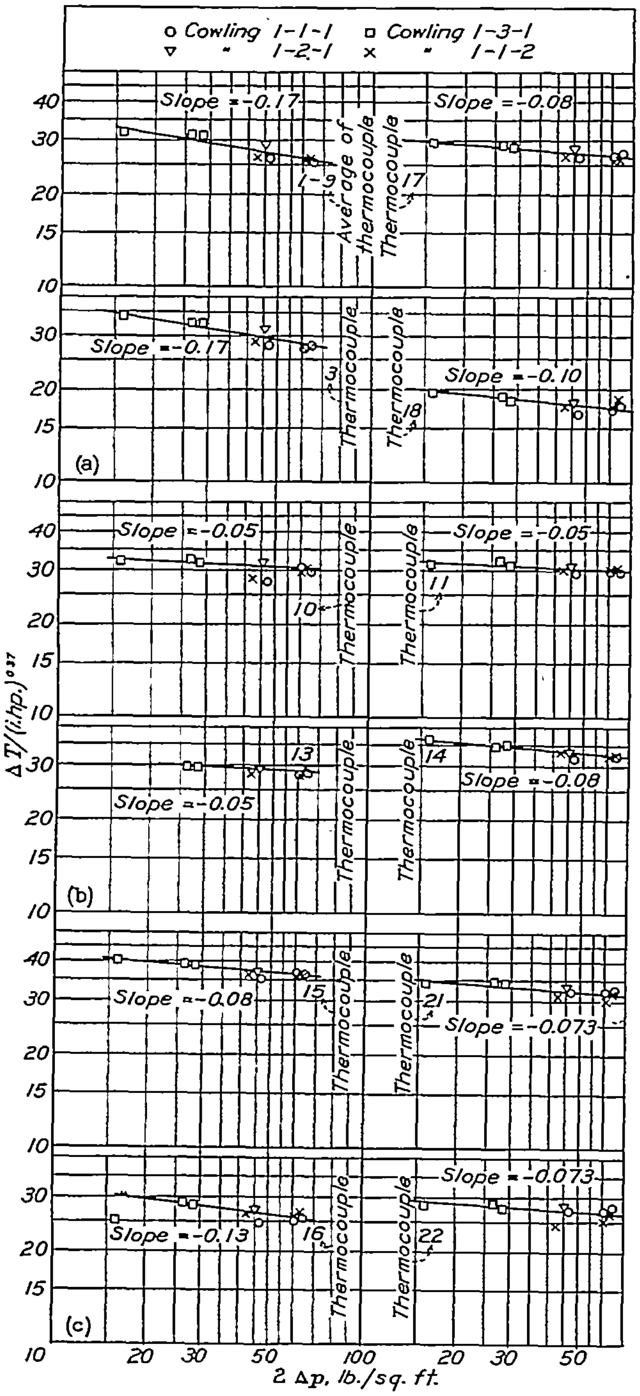


FIGURE 10.—The effect of Δp on $\Delta T/(\mathrm{i.\ hp.})^{0.27}$ for all cowlings with nose 1.

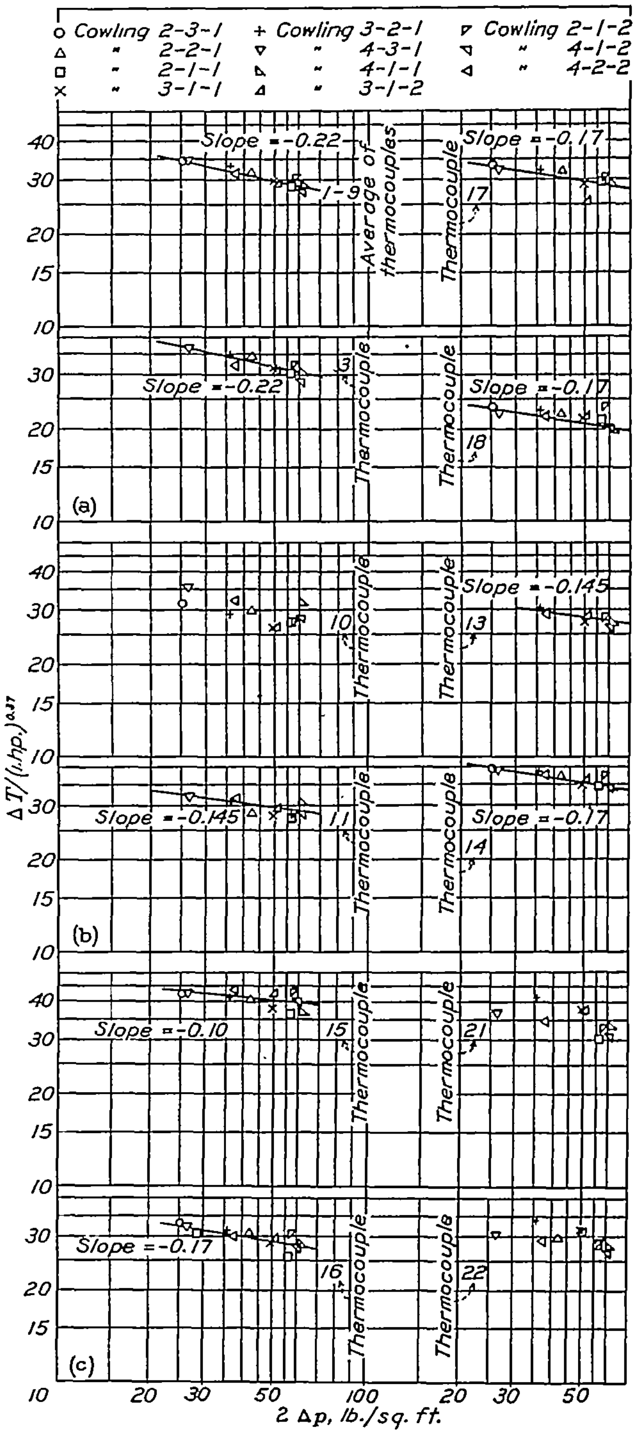


FIGURE 11.—The effect of Δp on $\Delta T/(\mathrm{i.\ hp.})^{0.27}$ for all cowlings with noses 2, 3, and 4.

DISCUSSION

In the presentation of the results, considerable emphasis has been placed on the fact that the temperatures on the front of the cylinder do not, in general, depend on Δp but upon large-scale turbulence. Such emphasis is justified by the general misconception that, if the required Δp is developed, the cooling problem has been solved. It is, however, quite possible to develop a desired Δp that will cool the baffled part of the cylinder satisfactorily yet be so deficient in large-scale turbulence on the front of the cylinder that little

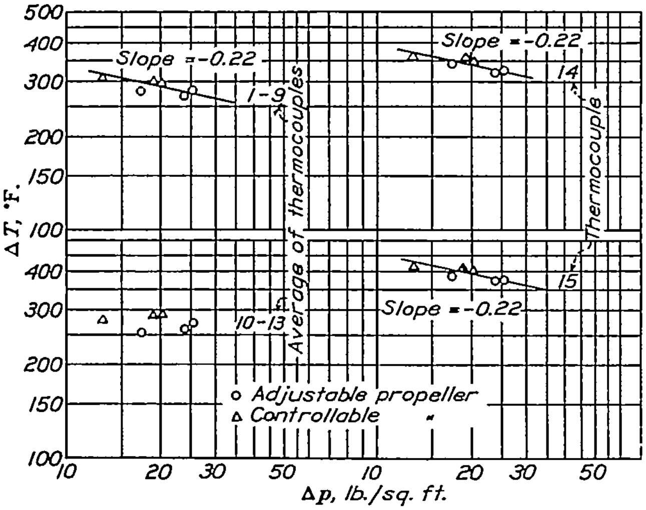


FIGURE 12.—The effect of Δp on temperature difference with adjustable and controllable propellers. Cowling 4-2-2; indicated horsepower, 430; specific fuel consumption, 0.57 pound per brake horsepower-hour; air speed, 80 to 110 miles per hour approximately.

cooling results there. A suction fan behind the engine would furnish just this type of cooling. A blower on the front, connected to the propeller may, or may not, develop the required turbulence for cooling. This turbulence, which is so important in the cooling of the unbaffled front of the cylinder and cylinder head, is of no importance in the cooling of the baffled and rear

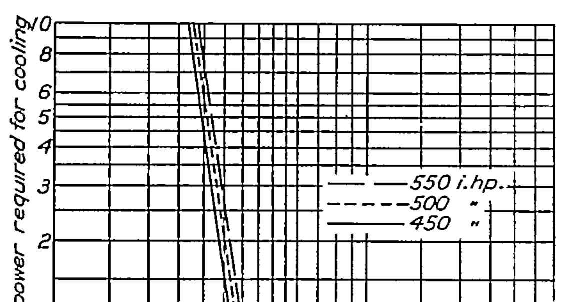


FIGURE 13.—Horsepower required for cooling for various temperature differences at several constant horsepowers. Noses 2, 3, and 4; thermocouples 1 to 9.

parts of the cylinder. Here the only consideration is the development of a value of Δp and, as a result, a velocity flow over the surface of the fins, sufficient to carry away the required amount of heat. The consistency of all the results for rear temperatures bear out this statement. A slope of -0.22 in the plots of Δp against $\frac{\Delta T}{(\text{i.hp.})^{0.37}}$ is found consistently throughout these tests for the baffled part of the cylinder. This slope is somewhat lower than the value given in reference 1. This difference is probably due to the difference in the location of the thermocouples in the two series of

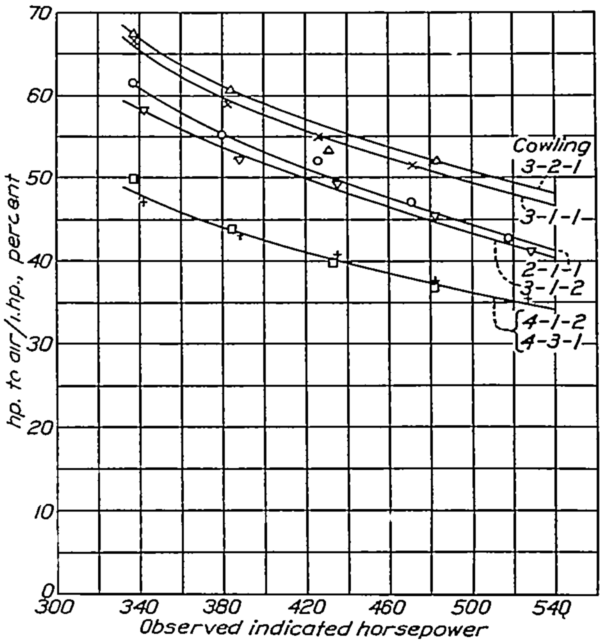


FIGURE 14.—The effect of indicated horsepower on the percentage of heat carried away by the cooling air for various cowling arrangements. Air speed, 100 miles per hour; engine speed, 1,800 r. p. m.

tests. In the former tests the thermocouples were located at the rear of the barrel itself; in the present series of tests the thermocouples were located on the rear spark-plug boss. It is quite possible that there is sufficient difference in the mechanism of cooling due to

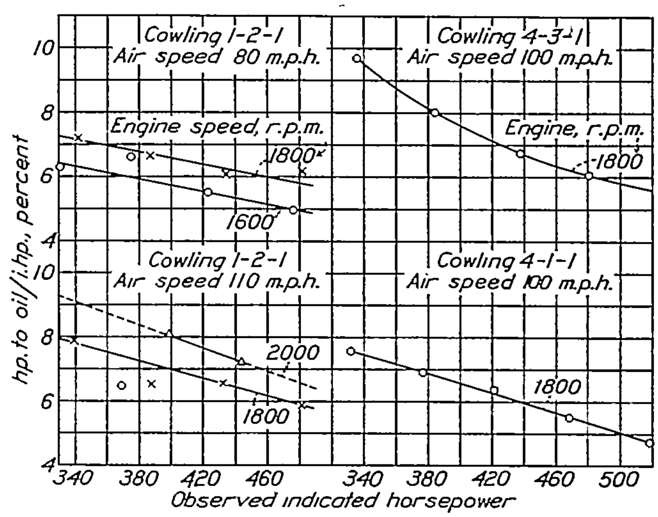


FIGURE 15.—The effect of indicated horsepower on the percentage of heat carried away by the oil for several cowling arrangements.

the finning near the spark-plug boss and the cylinder barrel to account for the difference in slope. It is also conceivable that the temperature of the spark-plug boss is affected less by velocity than that of the fins themselves. If this assumption is correct, the difference is in the right direction.

The effect of the propeller slipstream has also been emphasized in the present report. The misconception is often encountered that the propeller slipstream, regardless of the design of the propeller, increases the Δp available for cooling. References 1 and 2 have shown that, in general, this assumption is untenable. On the contrary, the Δp at a particular slipstream contraction is dependent on the blade-angle distribution, especially near the hub. Moreover, it has been pointed out that by designing for a large blowing action from the blade sections near the hub, a considerable increase in Δp can be realized. The large hub is not believed to contribute directly to the lower Δp. Indirectly, the difficulty encountered in designing a good airfoil section near the axis of the propeller limits the available blowing action.

No effect of engine speed on cooling could be found. With a given indicated horsepower and Δp the engine speed could be varied from 1,600 to 2,200 r. p. m. without any measurable deviation in temperature. It is obvious that, to the extent that Δp was changed, there was a corresponding effect on the rear temperature. It might be expected that the propeller would superimpose some flow that would improve the cooling on the front of the cylinder. No such effect could be found.

The percentage of the indicated horsepower required to cool varied from 1 to 1.5 and is based on the assumption that the Δp is developed at 100 percent efficiency. Reference 1 shows that the efficiency varies with both skirt shape and skirt opening. In the analysis of the problem it has been shown that the useful powei expended in cooling is proportional to $(\Delta p)^{3/2}$. It follows, then, that the values of 1 to 1.5 percent of the indicated horsepower apply to a particular Δp or to a particular air speed alone. At higher air speeds, with a given arrangement, a larger Δp will be developed and a correspondingly higher power will be used.

The limiting indicated horsepower at various values of Δp for three values of the temperature was found. Both the percentage of indicated horsepower required to cool and the limiting indicated horsepower, when considered together, bring out clearly the expensiveness of overcooling. The obvious recommendation is to decrease the skirt exit and thus decrease the Δp at high air speeds. It has been shown (reference 1) that by decreasing the skirt exit in the proper manner the exit orifice or pump could be made to act more efficiently. Thus the real cost of cooling will be lower than the corresponding decrease in Δp would indicate. The results presented here show that this engine, when developing 500 horsepower, will cool so that the hottest point (thermocouple 15) does not exceed 400° F. above cooling-air temperature with a Δp of 25 pounds per square foot. It has been shown (reference 1) that by using closer baffling this value can be appreciably reduced.

The amount of heat that must be dissipated to provide adequate cooling was determined. The present value, or any value, is useful only when all engine conditions, such as cylinder size, finning, baffling, temperature distribution on the cylinder surface, compression ratio, air-fuel ratio, and mechanical condition of the engine are reproduced. The relative values of heat dissipated at high and low values of the indicated horsepower are of the most importance. Comparatively, the results should be usable.

CONCLUSIONS

Tests on an R-1340 S1H1-G Pratt & Whitney Wasp engine with several cooling arrangements showed:

1. A pressure drop sufficient for cooling in climb under full power can be developed.
2. The controllable propeller had no beneficial effect on cooling and the adjustable propeller improved the cooling only slightly.
3. Equally good cooling, for a particular pressure drop, resulted from each of the cowlings tested.
4. With a given baffling and finning on the cylinders, the skirt is the controlling factor in cooling in climb.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *August 20, 1936.*

REFERENCES

1. Theodorsen, Theodore, Brevoort, M. J., and Stickle, George W.: Full-Scale Tests of N. A. C. A. Cowlings. T. R. No. 592, N. A. C. A., 1937.
2. Theodorsen, Theodore, Brevoort, M. J., and Stickle, George W.: Cooling of Airplane Engines at Low Air Speeds. T. R. No. 593, N. A. C. A., 1937.
3. Weick, Fred E., and Wood, Donald H.: The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. T. R. No. 300, N. A. C. A., 1928.
4. Gerrish, Harold C., and Voss, Fred: Mixture Distribution in a Single-Row Radial Engine. T. N. No. 583, N. A. C. A., 1936.
5. Schey, Oscar W., and Pinkel, Benjamin: Effect of Several Factors on the Cooling of a Radial Engine in Flight. T. N. No. 584, N. A. C. A., 1936.
6. Schey, Oscar W., and Ellerbrock, Herman H., Jr.: Performance of Air-Cooled Engine Cylinders Using Blower Cooling. T. N. No. 572, N. A. C. A., 1936.