NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 332

THE EFFECT OF COWLING ON CYLINDER TEMPERATURES AND PERFORMANCE OF A WRIGHT J-5 ENGINE

By OSCAR W. SCHEY AND ARNOLD E. BIERMANN

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - Price 15 cents

AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s		horsepower	hp
Speed		km/hr	k. p. h.	mi./hr.	m. p. h.
		m/s	m. p. s.	ft./sec.	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from C. G. to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/s, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

REPORT No. 332

THE EFFECT OF COWLING ON CYLINDER TEMPERATURES AND PERFORMANCE OF A WRIGHT J-5 ENGINE

By OSCAR W. SCHEY AND ARNOLD E. BIERMANN
Langley Memorial Aeronautical Laboratory

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

(An independent Government establishment, created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight. It consists of 15 members who are appointed by the President, all of whom serve as such without compensation.)

EXECUTIVE COMMITTEE

REPORT No. 332

THE EFFECT OF COWLING ON CYLINDER TEMPERATURES AND PERFORMANCE OF A WRIGHT J-5 ENGINE

By Oscar W. Schey and Arnold E. Biermann

SUMMARY

This report presents the results of tests conducted by the staff of the National Advisory Committee for Aeronautics to determine the effect of different amounts and kinds of cowling on the performance and cylinder temperatures of a standard Wright J-5 engine. These tests were conducted in conjunction with drag and propeller tests in which the same cowlings were used.

The engine was mounted in the nose of a cabin fuselage and placed in the air stream of the Committee's Twenty-Foot Propeller Research Tunnel, which is located at the Langley Memorial Aeronautical Laboratory. The power was measured by means of a torque dynamometer placed within the fuselage. Sixty-nine iron-constantan thermocouples and three recording pyrometers were used for obtaining the cylinder temperature measurements.

Four different cowlings were investigated, in tests herein reported, varying from the one extreme of no cowling on the engine to the other extreme of the engine completely cowled and the cooling air flowing inside the cowling through an opening in the nose and out through an annular opening at the rear of the engine. Each cowling was tested at air speeds of approximately 60, 80, and 100 miles per hour.

For the conventional type of engine cowling the results of these tests indicate that increasing the amount of cowling has the advantage of reducing the drag, but the disadvantage of increasing the cylinder barrel temperatures. Satisfactory cooling was obtained with the conventional cowling that covered 35 per cent of the cylinder cooling area. With the conventional cowling that covered 73 per cent of the cooling area the cylinder temperatures were excessive even though a large portion of the cooling air was permitted to flow inside the cowling through slots in the front of the cowling.

For the cabin fuselage with the N. A. C. A. cowling, which completely inclosed the engine and took in all of the cooling air through a 28-inch diameter opening in the nose, the drag was reduced 40 per cent at 100 miles per hour, as compared with the same unit with no cowling on the engine. The mean temperatures of the spark-plug boss and the cylinder head were slightly reduced for the same test conditions, but the barrel temperatures were increased.

The spark-plug boss temperatures, as used by many manufacturers, are a valuable indication of engine performance, but they alone should not be used as a criterion to determine the amount an engine can be cowled, since the barrel temperatures do not vary in parallel with them.

INTRODUCTION

Research on the air-cooled engine has been confined principally to the development of a reliable engine having adequate cooling and high power output per unit of weight. The problem of cowling has been a secondary consideration. Some interesting work, however, has been done, even though no systematic investigation has been conducted. In 1921 Colonel Clark designed an airplane powered with a Wright J-1 engine, having a cowling which completely inclosed the engine. (Reference 1.) The cooling air was taken inside the cowling through an opening in the front and was discharged through an annular opening in the rear of the engine. The Italian engineer, Piero Magni, also conducted tests on a similar cowling which he referred to as an "aerodynamic cowling." (Reference 2.) As far as the authors are aware, neither of these investigators made temperature measurements nor did they experience any cooling difficulties.

At the request of a large number of aircraft manufacturers the National Advisory Committee for Aeronautics decided to conduct a systematic investigation of the effect of different amounts and kinds of cowling on the drag, propulsive efficiency, cylinder temperatures, and performance of radial air-cooled engines.

The results of the drag and propulsive efficiency tests have been published in N. A. C. A. Technical Reports Nos. 313 and 314. (References 3 and 4.) The cylinder temperature and performance measurements, herein reported, were made on four different cowlings. These cowlings varied from the one extreme of no cowling on the engine cylinders to the other extreme of the engine completely cowled and the cooling air flowing in through an opening in the nose of the cowling and out through an annular opening at the rear of the engine. The tests for each cowling were conducted at air speeds of approximately 60, 80, and 100 miles per hour.

DESCRIPTION OF APPARATUS AND METHODS

The tests herein reported were conducted on a standard Wright "Whirlwind" engine of the J–5 series. The engine, mounted in the nose of a cabin fuselage, was placed in the air stream of the Committee's Twenty-Foot Propeller Research Tunnel. A complete description of this tunnel and test methods may be found in N. A. C. A. Technical Report No. 300. (Reference 5.)

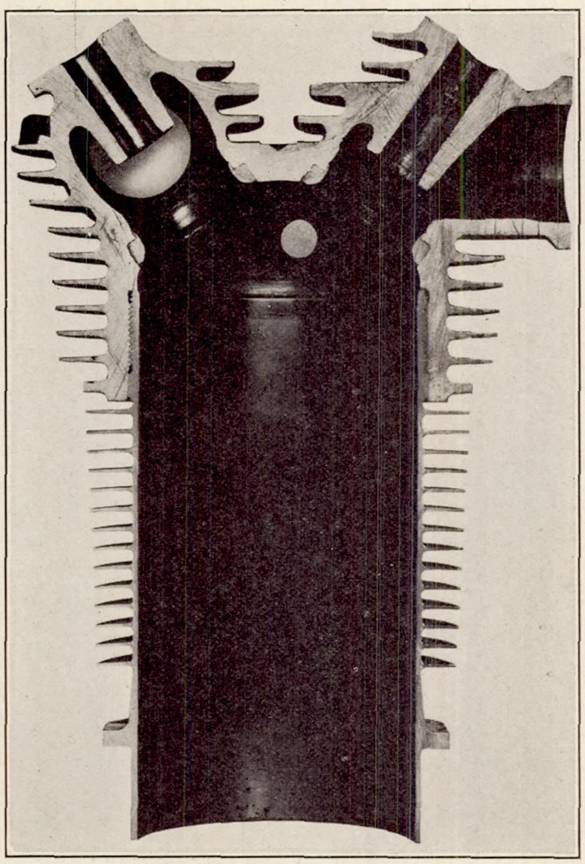


FIGURE 1.—Cross section of a Wright J–5 cylinder

This engine is of the 9-cylinder static-radial air-cooled type, having a 4½-inch bore, a 5½-inch stroke, and a 5.4 compression ratio. The engine is rated at 220 horsepower at 2,000 r. p. m. A Stromberg "NA–T4" carburetor was used, having three venturi chokes of 1 7/16 inches diameter and three Number 51 drill size main metering jets. The cylinders on this engine are of composite construction, having an aluminum head screwed and shrunk on a steel barrel. The walls of the steel cylinder barrel are 5/64 inch thick. The cross-section of this cylinder (fig. 1) shows the finning and construction.

Sixty-nine iron-constantan thermocouples and three multiple duplex recording pyrometers were used for measuring and recording the temperatures of cylinder head, barrel, and fin temperatures. Forty-seven thermocouples were attached to Cylinder Number 1 to obtain information on the distribution of temperatures over this cylinder. The remaining 22 thermocouples were distributed among the other eight cylinders so that information could be obtained on which to compare the operating temperatures of all cylinders and the engine performance. The thermocouples were made of 0.020-inch enameled wire and were electrically welded. An automatic electrically operated switch doubled the number of thermocouples that could be connected to each pyrometer. A reading was obtained on each thermocouple every three minutes.

The thermocouples on the head and fins were inserted into small holes and held in place by peening around the wires. Good thermal contact was obtained with this method. The thermocouples on the cylinder barrel were held firmly against the metal surface by means of clamp rings of narrow metal tape. For measuring the spark-plug-boss temperatures the thermocouples were embedded one-eighth inch below the metal surface at the root of the spark-plug bosses.

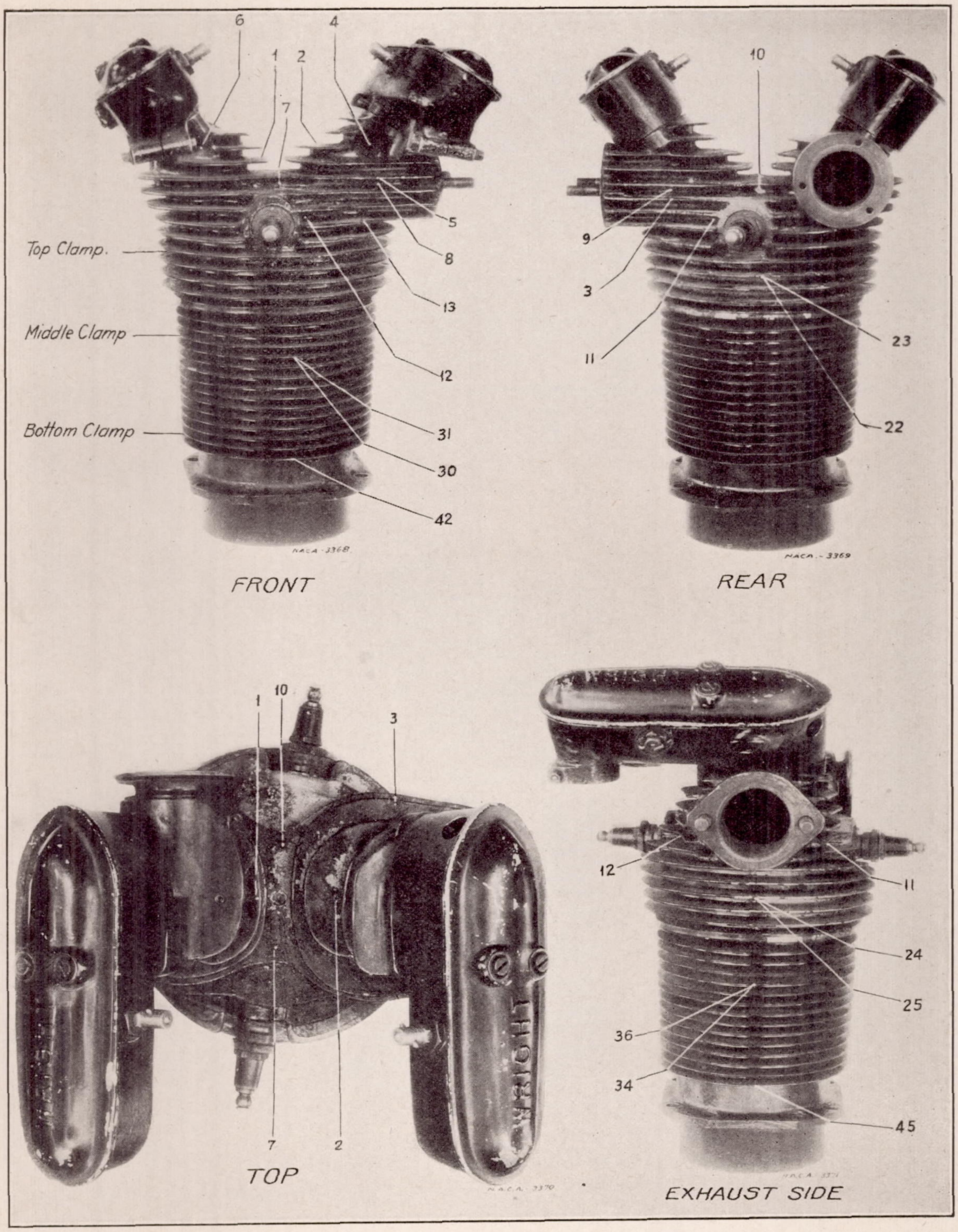


FIGURE 2.—Location of thermocouples on head and fins of cylinder No. 1

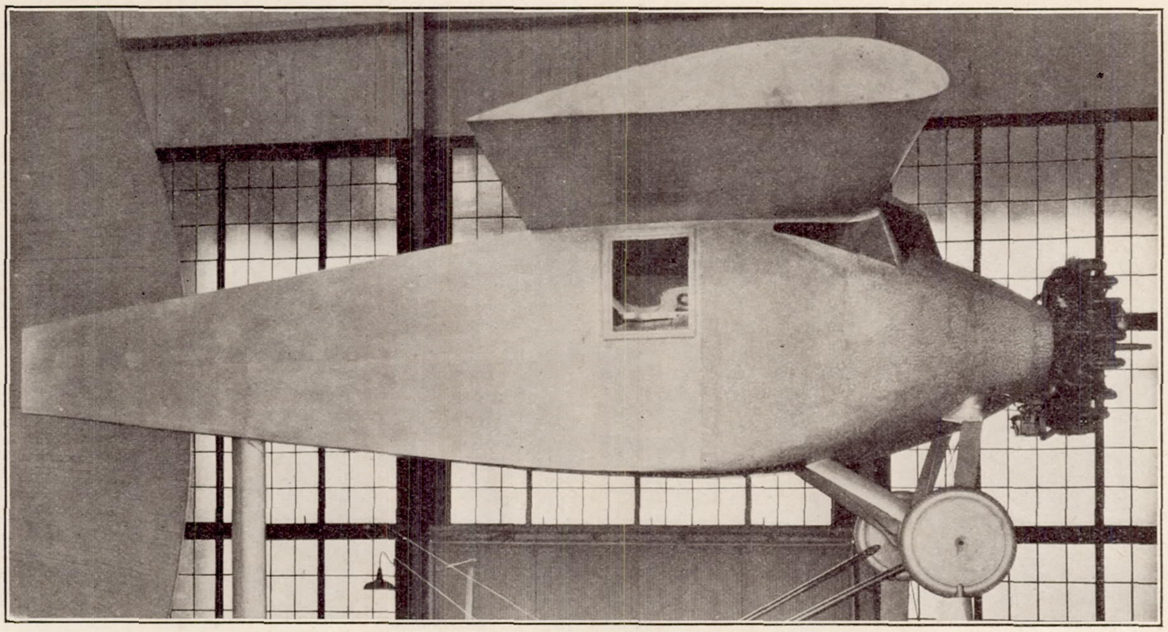


FIGURE 3.—View of fuselage and engine with cowling No. 4

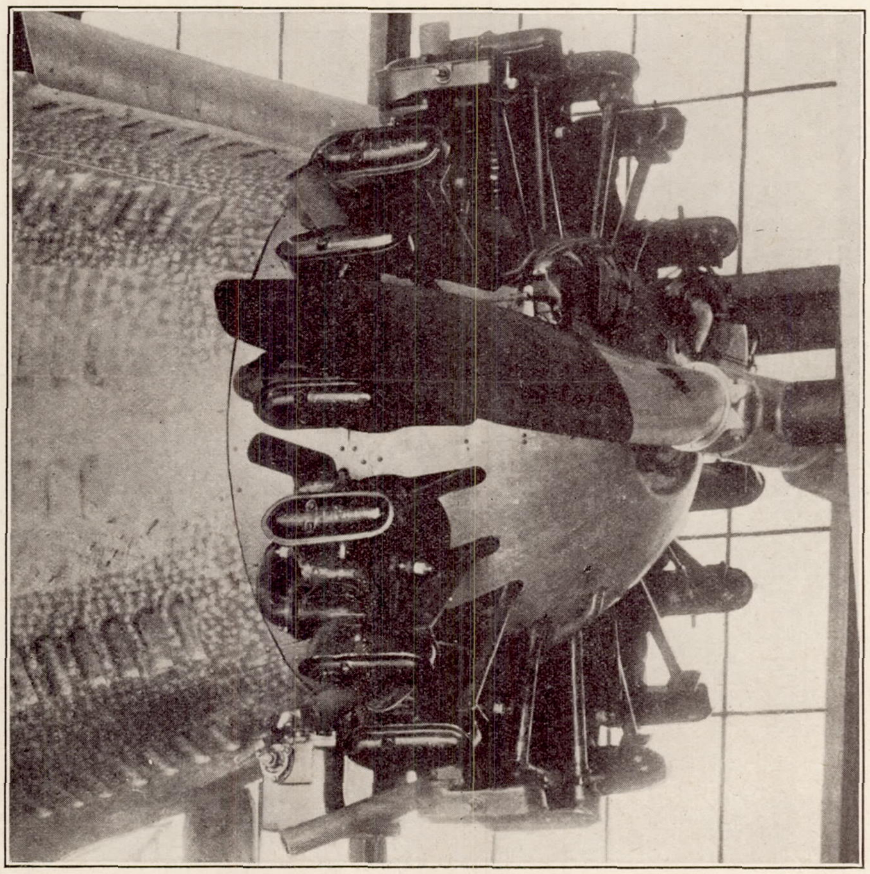


FIGURE 4.—Cowling No. 5

The general location of each thermocouple is given in Table I. The exact location of 23 of the 47 thermocouples on Cylinder Number 1 may be obtained from Figure 2, and the location of the other 24 may be obtained from any of the curves showing the temperatures measured under each clamp ring. Three clamp rings were used, located as follows: the bottom clamp ring between fins 1 and 2, the middle clamp ring between fins 11 and 12, and the top clamp ring between fins 18 and 19. Rear and front spark-plug-boss temperatures were measured on the other eight cylinders in the same location as shown for Thermocouples Numbers 11 and 12 on Cylinder Number 1 in Figure 2.

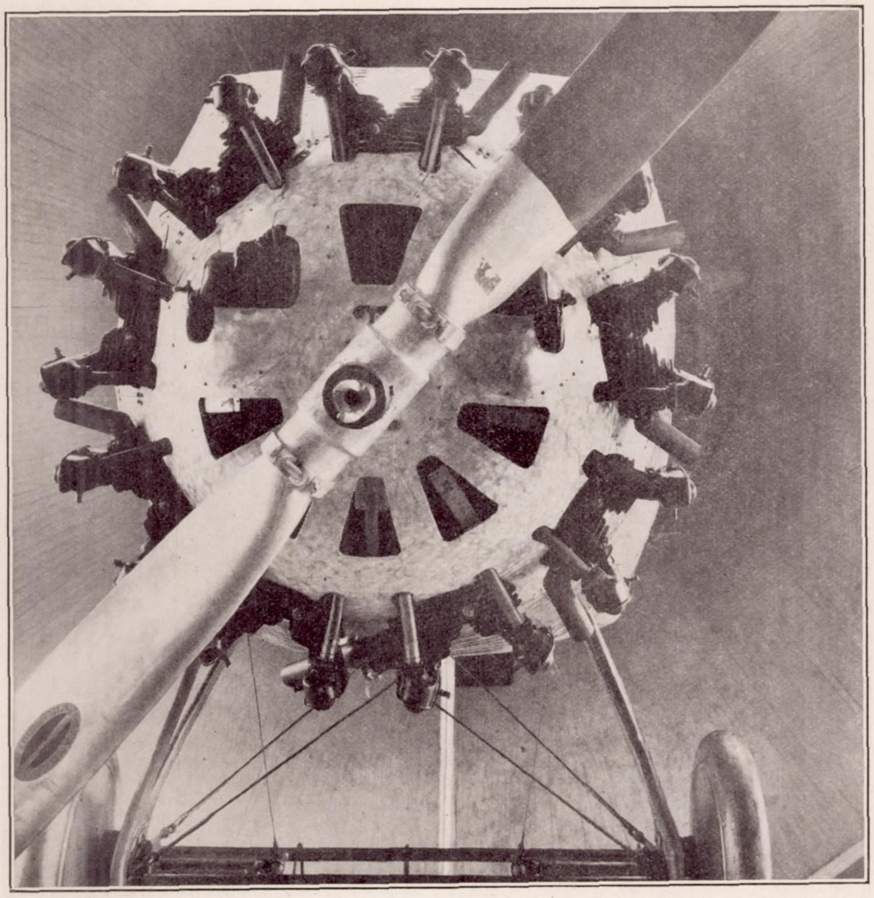


FIGURE 5.—Front view of cowling No. 7

In addition to the measurements of cylinder temperatures, the oil inlet, oil outlet, carburetor air, and cold junction temperatures were measured with electrical resistance thermometers. The fuel consumption was obtained from measurement of the time required to consume 2 pounds of fuel. Measurements were also obtained of the air speed, engine speed, and torque at full throttle. The engine torque was measured by means of a torque dynamometer placed within the fuselage. (References 3 and 5.) The same pitch setting was used on the propeller for all runs.

The total cooling area of each fin and surface above the mounting flange was carefully determined. By noting the number of fins below the cowling and where the cowling crossed the fins, the percentage of the total cooling area which was cowled could be computed.

The four cowlings for which cylinder temperature and performance measurements were obtained were selected from a series of 10 cowlings that had been constructed for drag tests. The first of these cowlings tested, designated as Number 4, did not cover any of the cylinder cooling area. Figure 3 shows this cowling with engine and fuselage as mounted ready for the test. The second cowling tested, designated as Number 5, covered 35 per cent of the cooling area of the cylinders (fig. 4). This cowling is similar to the conventional cowling used on commercial planes powered with radial engines. The third cowling tested, designated as

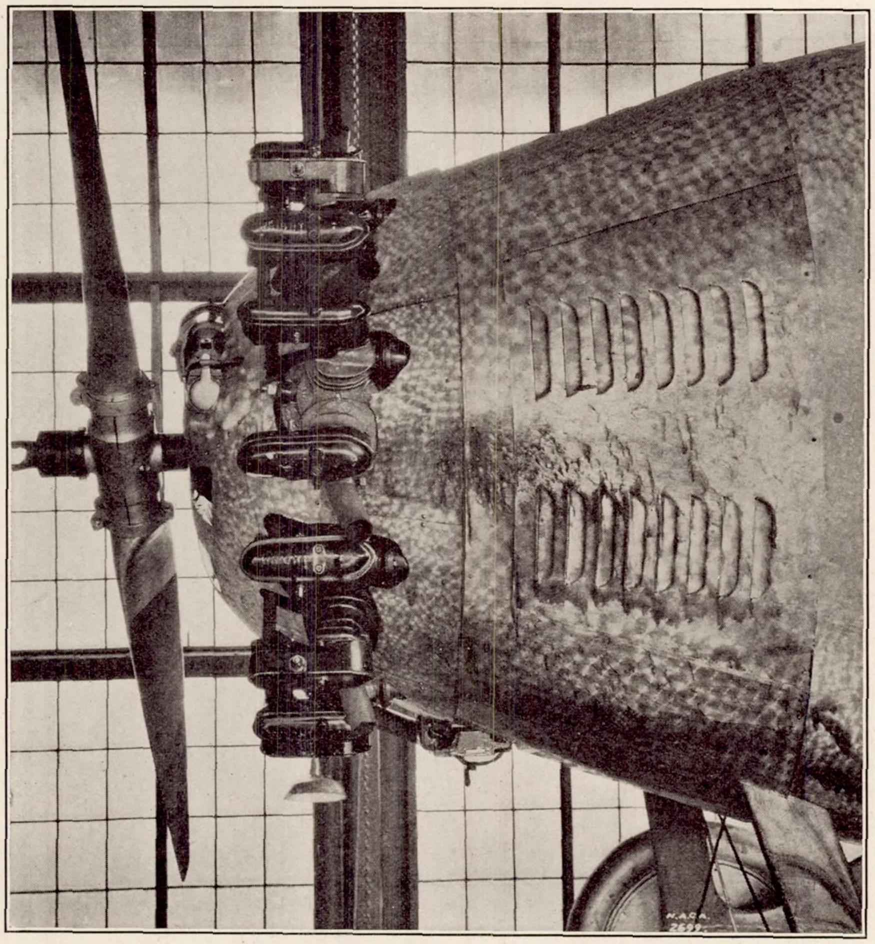


FIGURE 6.—Side view of cowling No. 7

Number 7, covered 73 per cent of the cooling area of each cylinder (figs. 5 and 6). This cowling probably covered a larger percentage of the total cooling area than any of the commercial cowlings now used. It had six slots cut in the nose to permit part of the cooling air to flow inside the cowling. The fourth cowling tested, designated as Number 10, inclosed the entire cooling area, the cowling being faired over the top of the cylinders and so designed as to permit the cooling air to flow inside the cowling and around the cylinders and cylinder heads (figs. 7 and 8). Cowling Number 10 was tested with deflectors between cylinders as shown in Figure 9. Each of these cowlings was tested at air speeds of 60, 80, and 100 miles per hour.

RESULTS

The results of tests on cylinder temperatures and engine performance with the four different cowlings tested are presented in Tables I and II and in Figures 10 to 16, inclusive.

Table I gives the location of each of the 69 thermocouples used. The maximum temperatures obtained at each point during tests on the four cowlings, at air speeds of approximately 60, 80, and 100 miles per hour, are also given in this table.

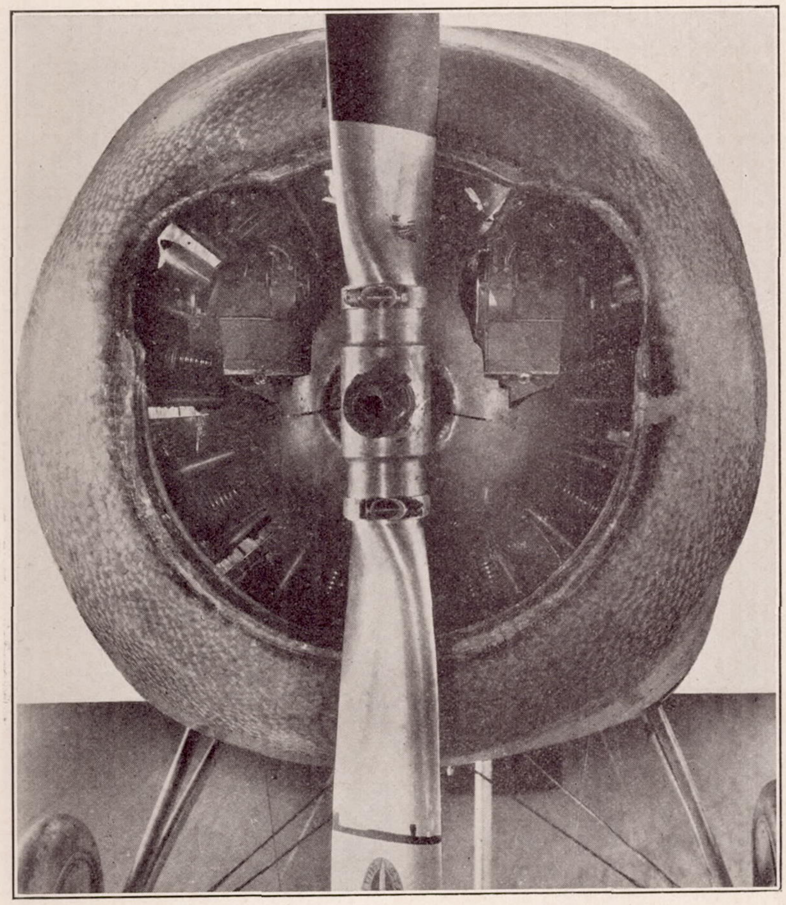


FIGURE 7.—Front view of cowling No. 10

Table II presents test data on engine speed, brake horsepower, fuel consumption, carburetor air temperature, oil-in temperature, and oil-out temperature. Data on air velocity, barometer, and room temperature are also included in this table.

The curves in Figure 10 present information on the variation of barrel temperatures on Cylinder Number 1 with changes in air speed. This information is given for the top, middle, and bottom clamps for each of the four cowlings tested.

A comparison of the barrel temperatures obtained with each cowling is shown in Figure 11. This information is given for the top, middle, and bottom clamps for air speeds of approximately 60, 80, and 100 miles per hour.

61466—29——2

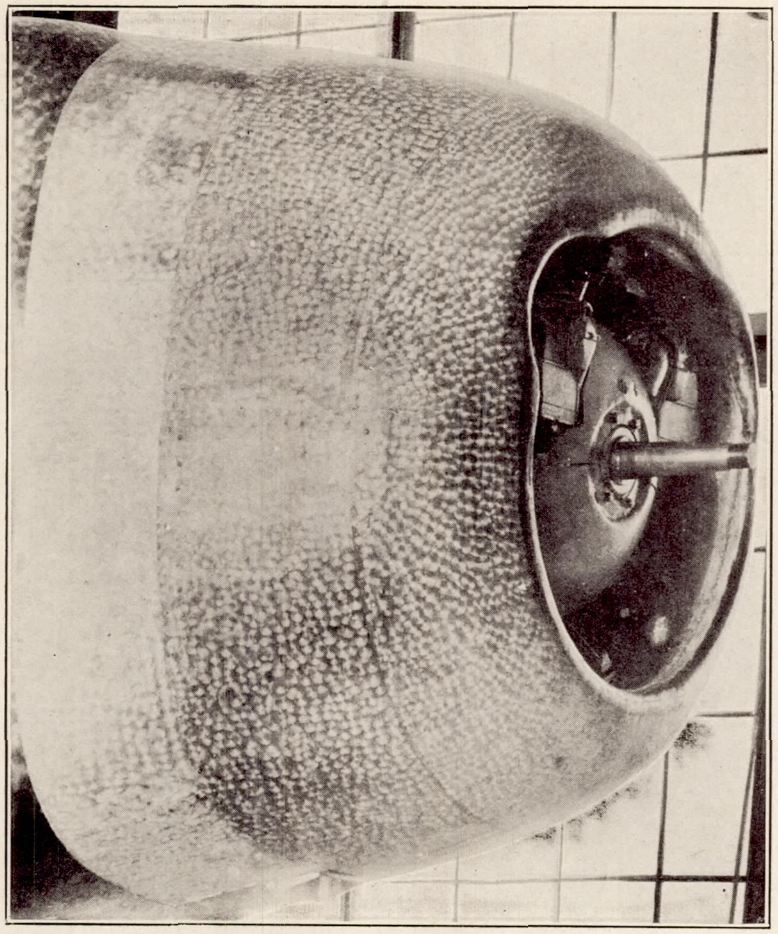


FIGURE 8.—Three-quarter side view of cowling No. 10

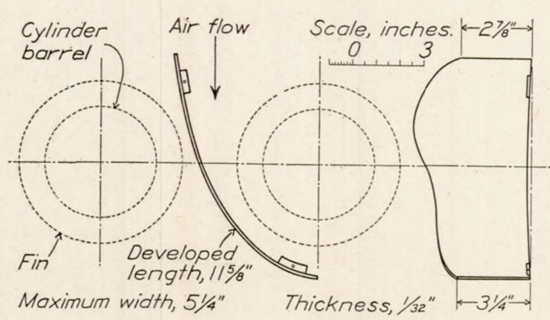


FIGURE 9.—Deflector used with cowling No. 10

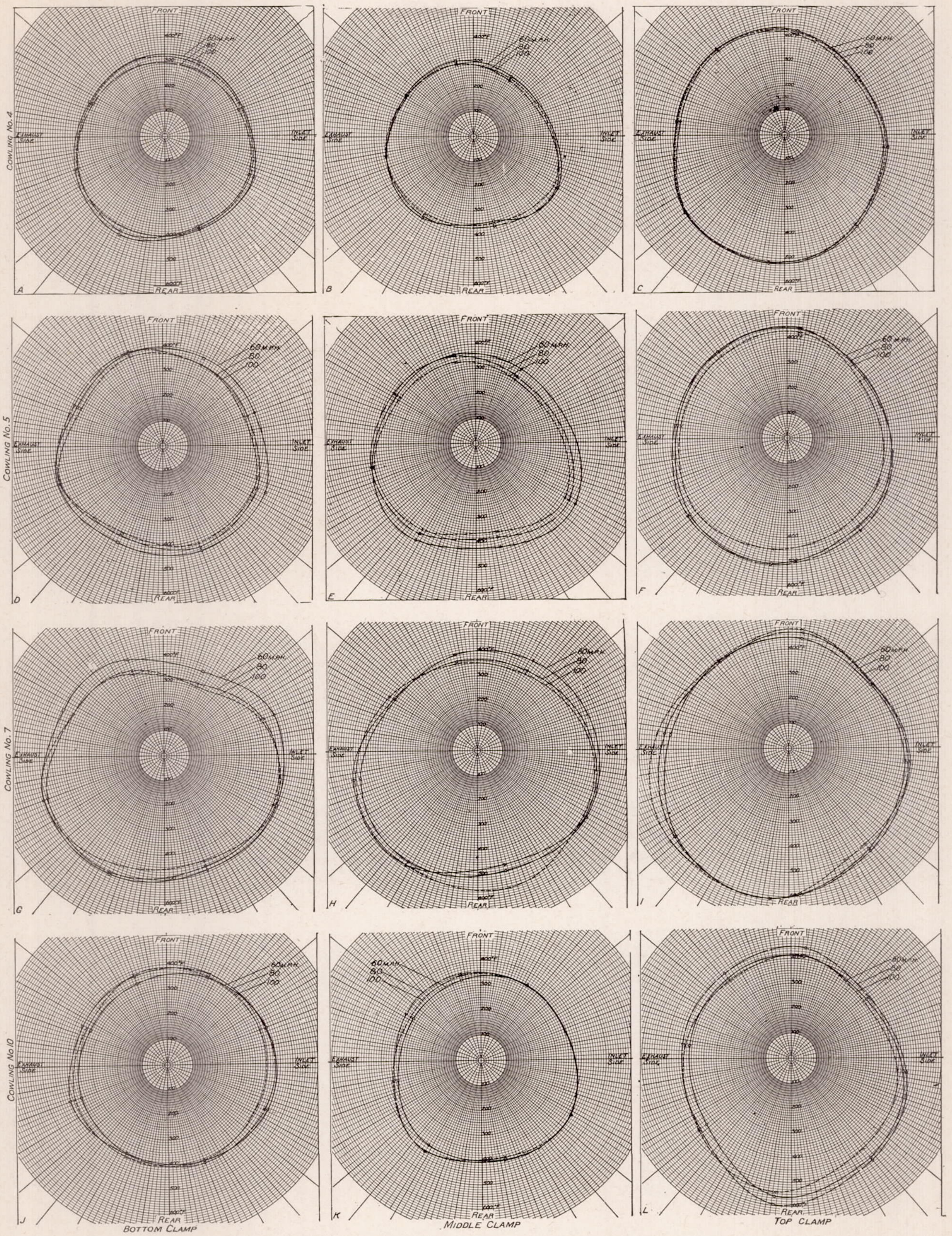


FIGURE 10.—Effect of air speed on cylinder barrel temperatures

In Figure 12 are presented the temperature measurements obtained on the front and rear spark-plug bosses. These temperatures are shown for each of the four cowlings tested at air speeds of approximately 60, 80, and 100 miles per hour. As these readings were taken on each cylinder, they are a good indication of engine performance.

The effect on cylinder barrel temperatures of slots in the nose of the cowling, so as to permit part of the cooling air to flow inside the cowling, is shown in Figure 13. These results are shown without slots and with four and six slots at air speeds of approximately 80 miles per hour. The tests without slots and with four slots were discontinued because of high temperatures.

Figure 14 shows the temperature variation obtained on Cylinder Number 1 for each of the four cowlings tested. These results are given for the front and rear spark-plug bosses and the top, middle, and bottom clamps, for air speeds of approximately 80 miles per hour.

Figure 15 presents information on the variation of power delivered to the propeller for each of the four cowlings for air speeds from approximately 60 to 100 miles per hour.

The distribution of temperatures over Cylinder Number 1 at an air speed of approximately 80 miles per hour is shown in Figure 16. The maximum and minimum temperatures for each clamp ring are also given in this figure.

DISCUSSION OF RESULTS—EFFECT OF COWLING ON CYLINDER TEMPERATURES

The manner in which an air-cooled engine is cowled greatly affects the cylinder temperatures. This effect is so large that a cylinder of indifferent design may, by a careful selection of cowling, operate more satisfactorily than a well-designed cylinder which is improperly cowled. The selection of a satisfactory cowling, however, is not dependent upon cooling alone, but also upon other factors, such as the drag, the propulsive efficiency, the service or type of airplane in which the engine is used, and whether it will be operating in a hot or cold climate.

The results of these tests indicate that if more than 35 per cent of the cooling area of a well-designed cylinder is cowled, the temperatures on the lower part of the cylinder barrel will be high. With Cowling Number 5, which covered 35 per cent of the cooling area of the cylinders, temperatures of 450° F. were obtained on the lower part of the barrel.

The curves in Figure 13 show the effect on cylinder barrel temperatures of increasing the amount of air flowing inside the cowling. These tests were conducted with Cowling Number 7. Temperatures greater than 600° F. were obtained on the lower part of the cylinders with this cowling, but by cutting six slots in the nose of the cowling these temperatures were reduced 270° F. in the front-lower part of the cylinder and 140° F. in the rear-lower part of the cylinder. The effect of these slots in reducing the barrel temperatures was greatest on the bottom of the barrel, but they also reduced the temperatures over 100° F. on the upper part of the barrel. Although these barrel temperatures were reduced considerably by the use of slots they are, nevertheless, excessive. The lowest barrel temperatures were obtained with Cowling Number 4. Cowlings Numbers 5 and 10 gave approximately the same barrel temperatures.

It is interesting to note that increasing the amount of cowling up to a certain limit reduces the spark-plug-boss temperatures. The curves in Figure 12 show that the rear-spark-plug-boss temperatures for Cowling Number 5, which covered 35 per cent of the cooling area, were lower than for Cowling Number 4, which did not cover any of the cooling area. This is due to the fact that with Cowling Number 5 more of the air is forced out to the head and past the upper part of the cylinders. The average temperatures for the rear spark-plug bosses on the seven hottest cylinders, at approximately 100 miles per hour, are 682, 675, 654, and 586° F. for Cowlings Numbers 4, 7, 10, and 5, respectively. From this it must be concluded that the degree to which an engine can be cowled is determined, not from spark-plug-boss temperatures, but from barrel temperatures; and, furthermore, that spark-plug-boss temperatures alone do not offer sufficient information on which to base any reliable conclusions.

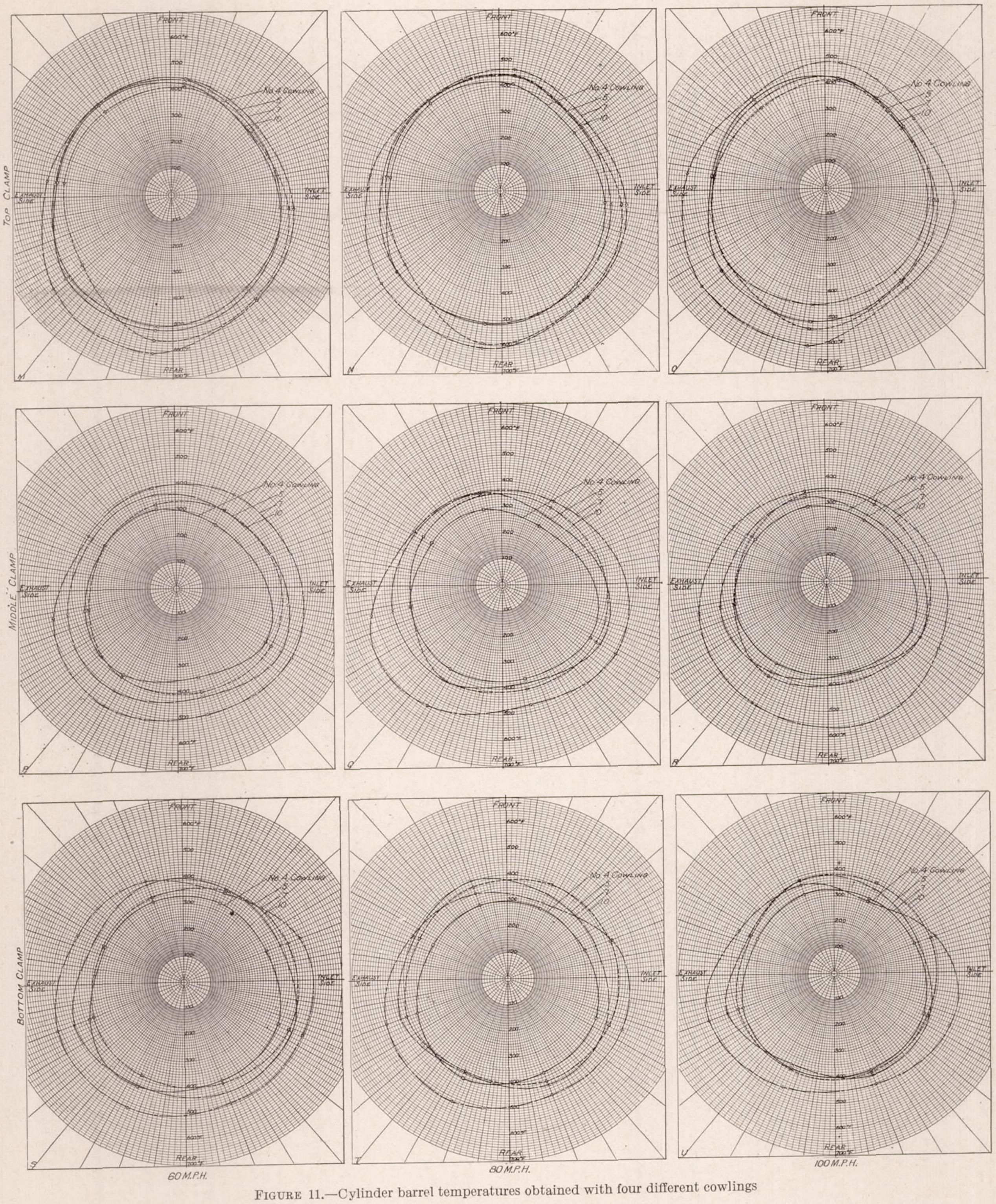


FIGURE 11.—Cylinder barrel temperatures obtained with four different cowlings

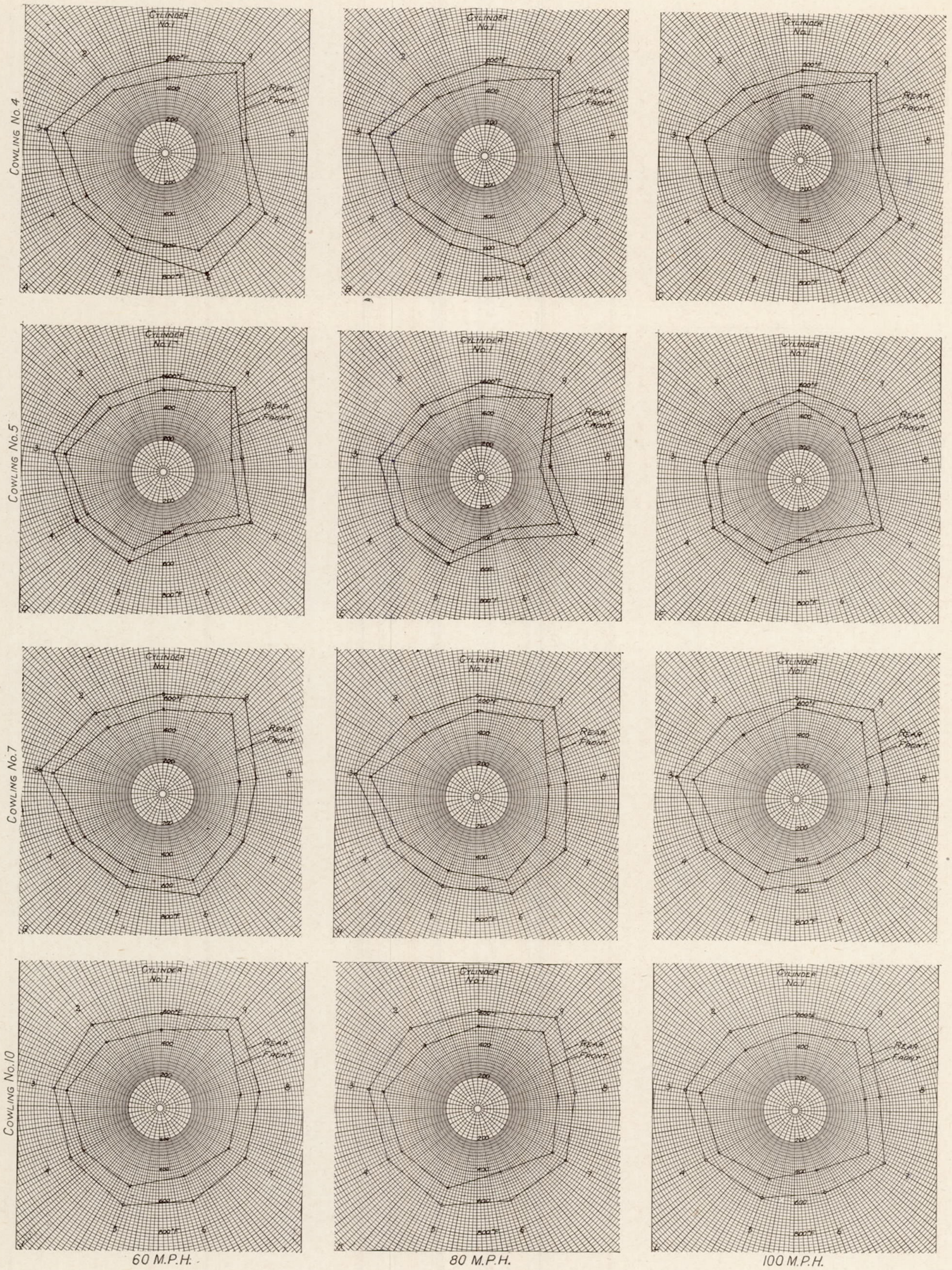


FIGURE 12.—Effect of cowling and air speed on spark-plug-boss temperatures

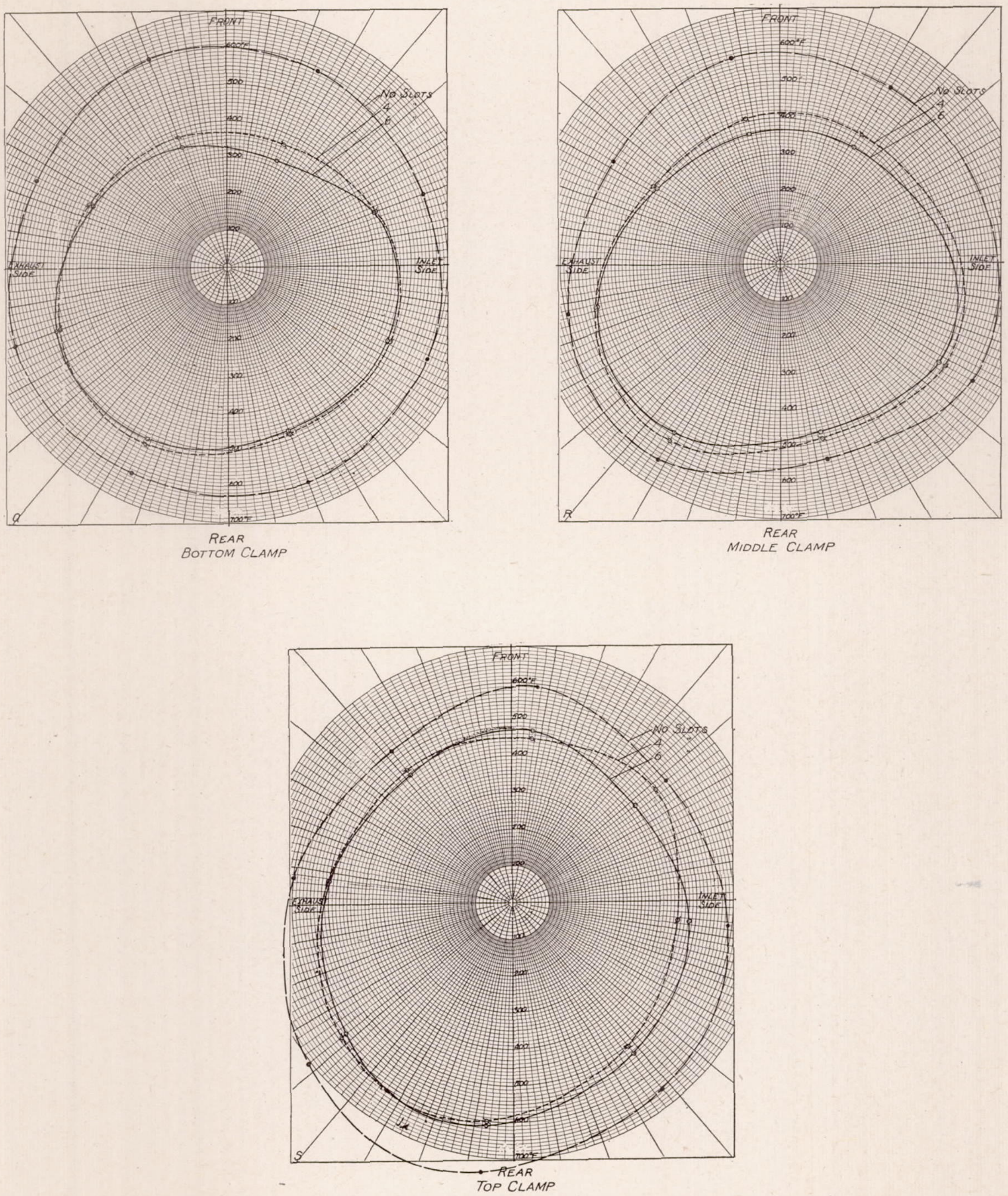
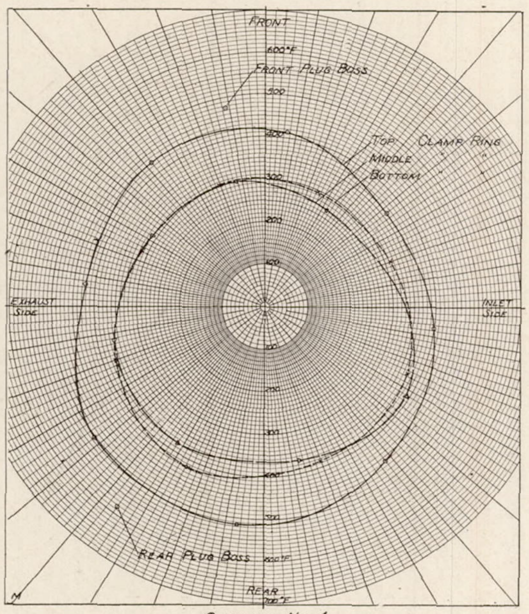
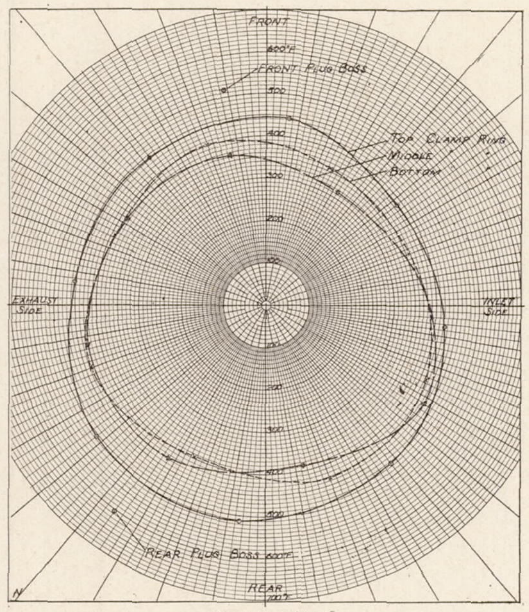


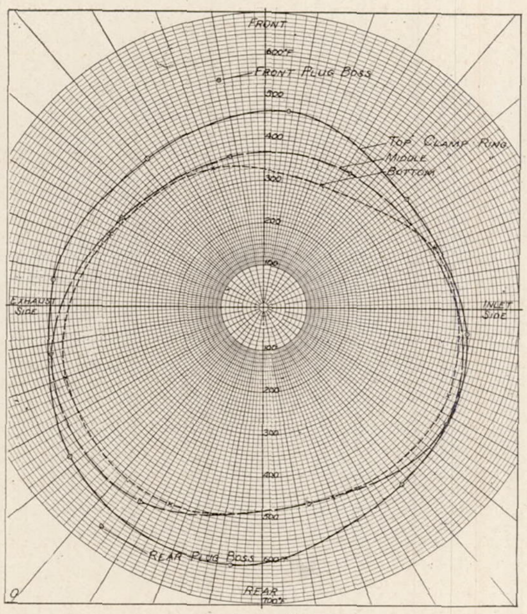
FIGURE 13.—Effect of slots in nose of cowling No. 7 on cylinder-barrel temperatures at 80 miles per hour



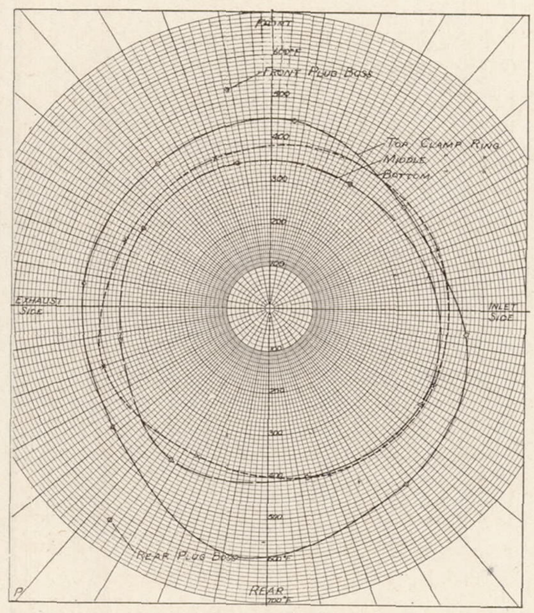
COWLING No. 4



COWLING No. 5



COWLING No. 7



COWLING No. 10

FIGURE 14.—Temperature distribution obtained on cylinder No. 1 at 80 miles per hour

The mean cylinder-head temperatures on the five hottest cylinders, at approximately 100 miles per hour, are 608, 604, 581, and 533° F. for Cowlings Numbers 7, 4, 10, and 5. These head temperatures, like spark-plug-boss temperatures, are no indication as to the amount an engine can be cowled, because the head temperatures decrease with increase in cowling, more of the cooling air being forced out to the head. If the amount of cowling on the lower part of the cylinder barrel is increased, the temperatures on this part of the cylinder will have exceeded the permissible limit long before the cylinder-head temperatures are as high as for an engine with no cowling. If the amount of cowling on the upper part of the cylinder is increased, the head temperatures will increase unless the cowling, like Number 10, is shaped so that the air can flow around the cylinder head.

The results of drag tests with a cabin fuselage, as reported in N. A. C. A. Technical Report Number 313, showed that Cowlings Numbers 5, 7, and 10 gave a reduction in drag of 4.8, 11.2, and 40 per cent, respectively, as compared with Cowling Number 4.

Information on the temperature distribution obtained with each cowling on Cylinder Number 1 at air speeds of 80 miles per hour is presented in Figures 14 and 16. These curves show that for all but Cowling Number 7 lower temperatures were obtained on the middle part of the cylinder than on the bottom. The temperature difference between the top and bottom of the cylinder varies from approximately 50° F. with Cowling Number 5 to over 150° F. with Cowlings Numbers 4 and 10. The circumferential temperature difference is surprisingly large, varying from about 75° F. on the bottom clamp with Cowlings Numbers 5 and 10 to about 200° F. on the top clamp with Cowlings Numbers 7 and 10. The high temperatures obtained in the rear of Cylinder Number 1 with Cowling Number 10 as shown in Figure 14 might be reduced by slight modification in the cowling.

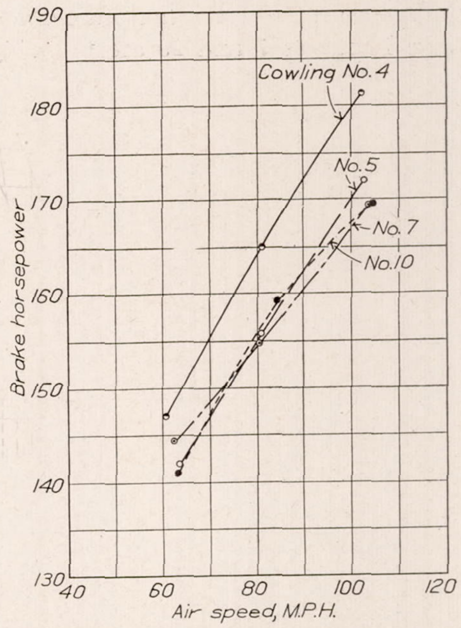


FIGURE 15.—The effect of cowling on the brake horsepower developed

It is interesting to note that for all cowlings except Number 10, in which air deflectors were used, the temperatures on the inlet side of the cylinder were lower than on the exhaust side. Considerably higher temperatures were obtained in tests without these deflectors. The flight tests that have been conducted with this cowling have also shown that the deflectors improve the cooling.

EFFECT OF AIR SPEED ON CYLINDER TEMPERATURES AND PERFORMANCE

The amount of cooling obtained with a given design of air-cooled engine is dependent principally upon the mass flow of air past the cylinders. In flight the amount of cooling air past the cylinders may be increased by increasing the speed of the airplane. However, this does not always result in reduced temperatures, because the power will have to be increased, except in a dive, to effect the increase in air speed. With an increase in power there is a proportional increase in the quantity of heat to be dissipated.

The relation between the air speed and the power developed at full throttle for each cowling is shown by the curves in Figure 15. It may be noted that an increase in air speed of 40 miles per hour results in an increase of approximately 30 horsepower in the power developed for each cowling, because of the higher engine speed.

Even though Cylinder Number 8 was not functioning properly, as the curves in Figure 12 indicate, considerably more power was developed with Cowling Number 4 than with any of the other cowlings. A cracked rocker-arm housing, discovered on Cylinder Number 8 at the end of the run with Cowling Number 4, was replaced at this time. The curves in Figure 12 for Cowling Number 5 show that Cylinders Numbers 6 and 8 were not developing their full power, or the temperatures would have been higher. The high temperatures obtained on Cylinder Number 6 during tests on Cowling Number 4 may have warped the valves, and it is possible that the valves in Cylinder Number 8 may also have been warped. As the engine had been completely overhauled between the tests on Cowlings Numbers 5 and 7, and since the cylinder temperatures indicate that all cylinders were functioning properly, the low powers with Cowlings Numbers 7 and 10 are probably due to high temperatures and detonation.

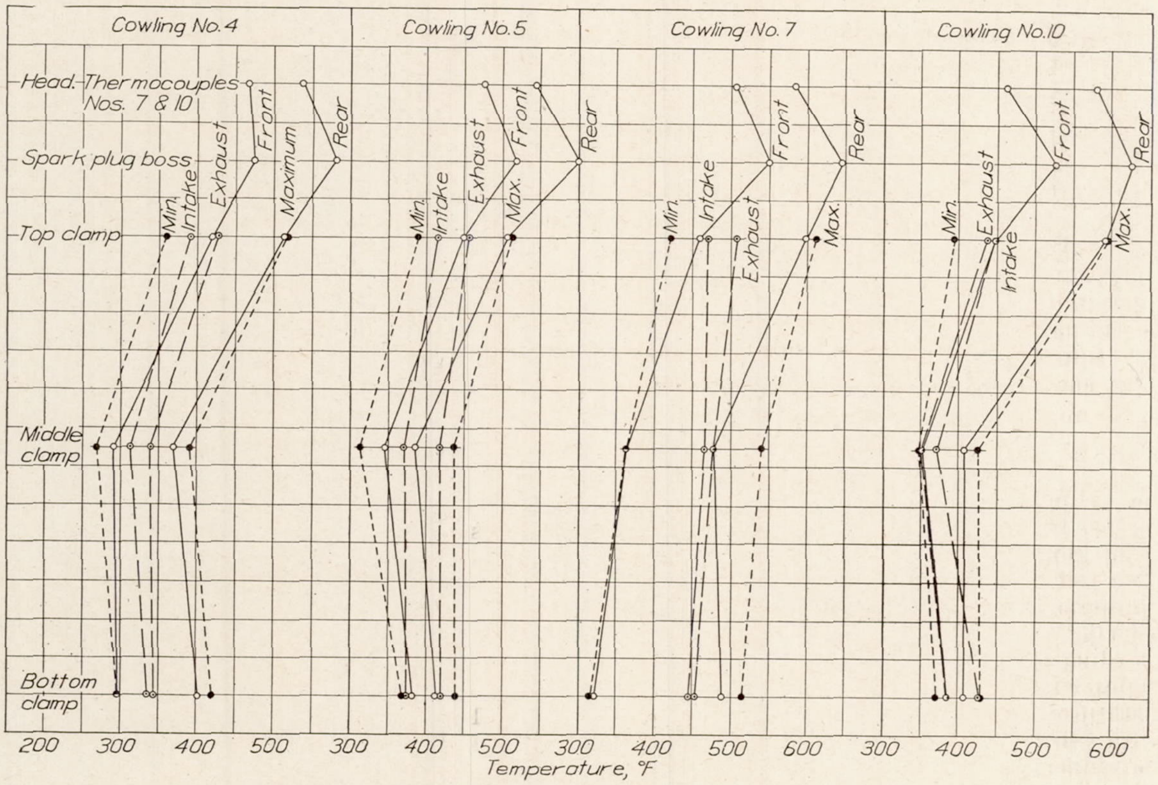


FIGURE 16.—Temperature distribution on cylinder No. 1 at 80 miles per hour

As the range of air speeds investigated in these full throttle tests was small compared to the range of air speeds obtained in climb and level flight even on a transport-type airplane, and since to effect an increase in air speed would require an increase in power, it is reasonable to expect that for these tests the one would very nearly offset the other and the temperature variation with change in air speed would be small. This is substantiated by the experimental evidence presented in the curves in Figures 10 and 12. The conditions for these tests were the same as a full throttle climb, the most severe conditions under which an air-cooled engine can operate.

Although the cylinder-barrel temperatures for Cowlings Numbers 4 and 5 (fig. 10) show very little effect, due to change in air speed, there is, however, sufficient variation to show that at approximately 60 miles per hour the temperatures are higher than for 80 or 100 miles per hour. The results obtained for Cowlings Numbers 7 and 10 do not show such consistent variation in barrel temperature with change in air speed.

By increasing the air speed from approximately 60 to 100 miles per hour the average rear-spark-plug-boss temperatures were reduced 25° to 50° F. for each cowling.

The cylinder-head temperatures for Cowlings Numbers 4 and 7 do not show a consistent variation with change in air speed. These temperatures show a reduction with increase in air speed for Cowlings Numbers 5 and 10. That this is true for Cowling Number 10 has been further verified by the fact that all airplanes of reasonably high speed have experienced no difficulty in cooling with this type of cowling.

That there is no change in the shape of these curves with change in air speed indicates that the directional flow of air is very nearly the same for each speed.

DISCUSSION OF TEST CONDITIONS

The maximum cylinder temperatures obtained during these full-throttle tests are higher than the maximum of 550° F. recommended by Heron for satisfactory operation. (Reference 6.) As these tests were conducted at full throttle on an engine of 5.4 compression ratio, using domestic aviation gasoline, and at high air stream temperatures, it is reasonable to believe that all cylinder temperatures were aggravated by detonation. Tests have shown that increasing the compression ratio up to the point where detonation starts reduces the temperatures, but that further increase so as to obtain detonation may cause a rise in cylinder-head temperatures of over 100° F. (Reference 6.) Recent tests completed by the Navy on an air-cooled engine of 5.16 compression ratio showed that when the amount of ethyl fluid in the fuel was decreased to 1½ cubic centimeters per gallon lower power and higher cylinder temperatures resulted because of detonation. (Reference 7.)

The error involved in making cylinder temperature measurements was small. Accurate measurements of these temperatures were obtained by assuring good thermal contact and by using small thermocouple wire and fairing it along the cylinder for some distance from the hot junction so that no heat would be conducted from the hot junction. High resistance pyrometers were used so as to reduce to a minimum the effect that any change in resistance of long leads might have on the readings. The pyrometers were calibrated with the same leads used in the tests, and the cold junction correction was applied to all readings.

CONCLUSIONS

The results of these tests indicate that not over 35 per cent of the cooling area of the cylinders of a Wright series J-5 engine should be cowled without permitting part of the cooling air to flow inside the cowling. With 73 per cent of the cooling area cowled barrel temperatures will be excessive, even though large slots are provided so that part of the cooling air may flow inside the cowling.

An increase in air speed from approximately 60 to 100 miles per hour, at full-throttle propeller loads, resulted in only a slight decrease in cylinder temperatures.

The spark-plug-boss temperatures alone should not be used as a criterion of engine cowling, but, instead, readings should be taken on several points on the barrel if the lower part of the cylinder is cowled and on several points on the head if the cowling completely incloses the engine.

Cowling Number 10, at 100 miles per hour, effects a 40 per cent reduction in drag as compared with the uncowled engine. The mean cylinder-head temperatures obtained with this cowling were less than those obtained with no cowling, but the barrel temperatures were slighlty higher. It is believed that the cylinder-head temperatures could be further reduced by slight modifications in this cowling, and it is also believed that the power loss of approximately 7 per cent indicated with Cowling Number 10 would not be present at the higher air speeds obtained in flight.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *May 2, 1929.*

REFERENCES AND BIBLIOGRAPHY

Reference 1. Aviation, March 23, 1929, xxvi, 12, 898.

Reference 2. Cooling of air-cooled engines by forced circulation of air. N. A. C. A. Technical Memorandum No. 385, 1926.

Reference 3. Weick, Fred E.: Drag and cooling with various forms of cowling for a "Whirlwind" radial air-cooled engine. N. A. C. A. Technical Report No. 313, Part I, 1928.

Reference 4. Weick, Fred E.: Drag and cooling with various forms of cowling for a "Whirlwind" radial air-cooled engine. N. A. C. A. Technical Report No. 314, Part II, 1928.

Reference 5. Weick, Fred E., and Donald H. Wood: The 20-foot propeller research tunnel of the National Advisory Committee for Aeronautics. N. A. C. A. Technical Report No. 300, 1928.

Reference 6. Heron, S. D.: Air-cooled cylinder design and development. Trans. Soc. Auto. Eng., 1922, xvii, Part I, 347–430.

Reference 7. Ballard, J. D.: Test of Pratt and Whitney Model R–1300 engine and investigation of relation between exhaust flame temperatures and air fuel mixture ratios on aircraft engines. Report by Bureau of Aeronautics, U. S. Navy Department, 1928, Serial No. AEL–207.

Gibson, A. H.: Exhaust and cylinder head temperatures in high-speed petrol engines. Proc. Inst. Mech. Eng., 1923, ii, 4–6, 1045–1091.

Eade, W. F.: Investigation of heat distribution on J–5 cylinders. Report by Bureau of Aeronautics, U. S. Navy Department, 1927, Serial No. AEL–195.

TABLE I

CYLINDER HEAD, BARREL, AND FIN TEMPERATURES (DEGREES FAHRENHEIT) OBTAINED IN COWLING TESTS ON A WRIGHT J-5 ENGINE

No.	Location of thermocouple [NOTE.—Right and left are looking front from the cockpit]	Cowling No. 4				Cowling No. 5			Cowling No. 7				Cowling No. 10		
		Air speeds, M. P. H.				Air speeds, M. P. H.			Air speeds, M. P. H.				Air speeds, M. P. H.		
		22	60	80	100	60	80	100	[1] 80	60	80	100	60	80	100
1	Cylinder No. 1, fin tip, left side of inlet passage	360	346	330	335	346	462	315	430	371	368	353	367	365	353
2	Cylinder No. 1, center of head, top of exhaust passage	532	512	507	500	502	494	478	530	510	511	507	535	542	541
3	Cylinder No. 1, fin tip, rear of exhaust passage	500	495	480	483	481	447	450	498	469	461	458	522	536	518
4	Cylinder No. 1, on front side of exhaust valve guide	450	445	432	438	420	405	402	431	425	414	422	442	458	443
5	Cylinder No. 1, near fin tip, front of exhaust passage	420	390	363	372	369	343	325	388	382	370	368	395	400	382
6	Cylinder No. 1, front side of inlet valve guide	242	236	218	220	233	210	201	275	248	229	225	232	233	214
7	Cylinder No. 1, in center of head over front spark plug	489	475	468	454	487	478	460	588	492	509	488	475	463	473
8	Cylinder No. 1, front of head, side of exhaust passage	475	459	447	441	458	440	425	481	461	462	458	470	475	470
9	Cylinder No. 1, rear of head in side of exhaust passage	532	522	512	510	520	508	490	563	527	525	520	556	578	570
10	Cylinder No. 1, in center of head over rear spark plug	565	538	538	527	555	545	519	660	579	585	573	562	580	563
11	Cylinder No. 1, in left side of rear spark-plug boss	600	588	583	573	608	602	575	739	637	646	644	600	628	622
12	Cylinder No. 1, in left side of front spark-plug boss	514	475	475	470	522	519	507	638	541	550	585	497	528	498
13	Cylinder No. 1, fin tip, left of front spark-plug boss	422	408	398	408	428	444	425	566	440	470	489	394	430	418
14	Cylinder No. 1, under top clamp ring, right, rear	490	471	460	459	455	473	420	655	519	528	493	510	523	463
15	Cylinder No. 1, under top clamp ring, right	442	418	400	411	420	423	390	590	469	482	490	450	464	428
16	Cylinder No. 1, under top clamp ring, right, front	400	379	360	377	397	390	370	531	415	422	425	381	395	368
17	Cylinder No. 1, under top clamp ring, front	442	428	413	422	441	444	427	591	448	470	484	414	448	417
18	Cylinder No. 1, under top clamp ring, left, front	464	443	430	439	449	443	422	538	450	445	452	409	431	396
19	Cylinder No. 1, under top clamp ring, left	440	438	422	435	442	453	429	600	477	500	530	410	438	428
20	Cylinder No. 1, under top clamp ring, left, rear	528	510	504	505	495	505	469	708	572	578	601	430	462	470
21	Cylinder No. 1, under top clamp ring, rear	547	522	517	515	507	512	450	741	612	612	610	561	595	544
22	Cylinder No. 1, center of fin 18, in the rear	498	477	472	473	450	443	392	683	558	558	530	498	529	475
23	Cylinder No. 1, tip of fin 18, in the rear	477	461	460	453	449	428	388	660	538	548	518	469	485	432
24	Cylinder No. 1, tip of fin 18, on left side	412	411	400	395	401	416	370	518	393	433	450	367	401	361
25	Cylinder No. 1, center of fin 18, on left side	455	450	440	429	482	480	450	609	502	531	563	457	475	476
26	Cylinder No. 1, under middle clamp, rear	370	350	370	359	429	388	365	550	498	473	569	409	410	397
27	Cylinder No. 1, under middle clamp, right, rear	398	399	391	378	468	438	420	614	513	508	500	422	420	419
28	Cylinder No. 1, under middle clamp, right	-----	-----	-----	-----	-----	-----	-----	550	335	245	310	-----	-----	-----
29	Cylinder No. 1, under middle clamp, right, front	280	289	269	279	350	314	300	567	421	376	362	351	350	348
30	Cylinder No. 1, center of fin 11, front	233	258	241	230	291	283	260	520	325	291	273	265	281	273
31	Cylinder No. 1, tip of fin 11, front	174	205	185	180	232	216	200	440	279	227	208	207	218	210
32	Cylinder No. 1, under middle clamp, front	302	312	300	298	368	361	335	580	397	366	358	330	353	349
33	Cylinder No. 1, under middle clamp, left, front	298	318	312	317	372	385	353	535	390	394	412	318	352	333
34	Cylinder No. 1, center of fin 11, on left side	233	252	241	249	310	310	293	488	375	404	362	449	251	244
35	Cylinder No. 1, under middle clamp, left	338	360	360	360	428	430	419	595	482	511	502	342	357	362
36	Cylinder No. 1, tip of fin 11, on left side	181	206	195	207	240	250	242	403	330	335	297	203	228	209
37	Cylinder No. 1, under middle clamp, left, rear	401	387	379	368	458	428	408	630	528	543	545	398	427	425
38	Cylinder No. 1, under bottom clamp, rear, to right	382	399	385	396	449	434	418	630	493	477	453	410	418	405
39	Cylinder No. 1, under bottom clamp, right, to rear	393	391	370	379	451	414	402	600	494	480	488	439	426	394
40	Cylinder No. 1, under bottom clamp, right, to front	330	333	313	328	390	359	343	568	470	425	411	420	419	393
41	Cylinder No. 1, under bottom clamp, front, to right	322	330	296	318	389	358	360	590	373	320	305	381	399	383
42	Cylinder No. 1, tip of fin 1, front	232	255	224	242	323	314	303	556	315	248	242	289	319	330
43	Cylinder No. 1, under bottom clamp, front, to left	309	330	302	328	398	403	383	608	412	350	365	347	377	383
44	Cylinder No. 1, under bottom clamp, left, to front	303	330	315	324	378	391	360	572	443	400	401	337	372	353
45	Cylinder No. 1, tip of fin 1, left	249	268	250	262	320	318	306	514	435	380	363	264	318	280
46	Cylinder No. 1, under bottom clamp, left, to rear	368	382	370	371	447	438	437	618	512	496	512	367	412	392
47	Cylinder No. 1, under bottom clamp, rear, to left	412	433	418	398	428	395	382	620	523	517	479	388	390	403
48	Cylinder No. 2, in left side of front spark-plug boss	531	512	477	468	529	496	461	568	549	521	532	540	528	500
49	Cylinder No. 2, in left side of rear spark-plug boss	613	610	580	572	620	587	551	695	671	657	673	681	668	650
50	Cylinder No. 2, in center of head, over rear spark plug	568	550	521	519	555	525	496	603	578	549	558	640	650	617
51	Cylinder No. 3, in left side of front spark-plug boss	641	659	620	617	630	579	531	665	708	687	665	600	608	610
52	Cylinder No. 3, in left side of rear spark-plug boss	750	777	742	733	701	660	611	770	790	788	779	682	701	710
53	Cylinder No. 3, in center of head, over rear spark plug	631	737	692	661	638	614	549	717	733	725	682	-----	-----	-----
54	Cylinder No. 4, in left side of front spark-plug boss	598	568	549	550	551	538	548	627	566	558	560	556	554	553
55	Cylinder No. 4, in left side of rear spark-plug boss	682	662	643	650	627	615	623	700	651	647	659	650	658	649
56	Cylinder No. 4, in center of head, over rear spark plug	632	607	589	590	578	560	569	645	583	572	570	-----	-----	569
57	Cylinder No. 5, in left side of front spark-plug boss	571	571	502	502	528	508	487	520	528	507	509	530	539	468
58	Cylinder No. 5, in left side of rear spark-plug boss	665	656	603	595	616	590	570	625	633	612	618	659	653	599
59	Cylinder No. 5, in center of head, over rear spark plug	599	598	545	550	560	542	530	565	588	552	565	612	610	558
60	Cylinder No. 6, in left side of front spark-plug boss	639	655	612	622	360	351	347	378	582	563	431	455	428	404
61	Cylinder No. 6, in left side of rear spark-plug boss	759	812	742	757	426	421	418	465	685	658	548	625	616	558
62	Cylinder No. 6, in center of head, over rear spark plug	704	731	674	693	399	390	382	424	703	682	576	662	657	590
63	Cylinder No. 7, in left side of front spark-plug boss	610	628	588	607	551	572	541	587	500	502	496	502	549	535
64	Cylinder No. 7, in left side of rear spark-plug boss	732	743	733	735	641	702	615	728	597	655	601	626	642	657
65	Cylinder No. 8, in left side of front spark-plug boss	492	497	448	463	440	383	400	465	496	465	471	517	517	449
66	Cylinder No. 8, in left side of rear spark-plug boss	481	525	466	503	508	447	468	550	602	579	583	637	628	545
67	Cylinder No. 8, in center of head over rear spark plug	393	458	371	435	438	393	402	481	473	483	472	428	438	488
68	Cylinder No. 9, in left side of front spark-plug boss	668	680	651	668	669	661	440	673	673	640	640	650	644	577
69	Cylinder No. 9, in left side of rear spark-plug boss	750	758	718	730	700	695	560	756	801	759	750	750	768	688

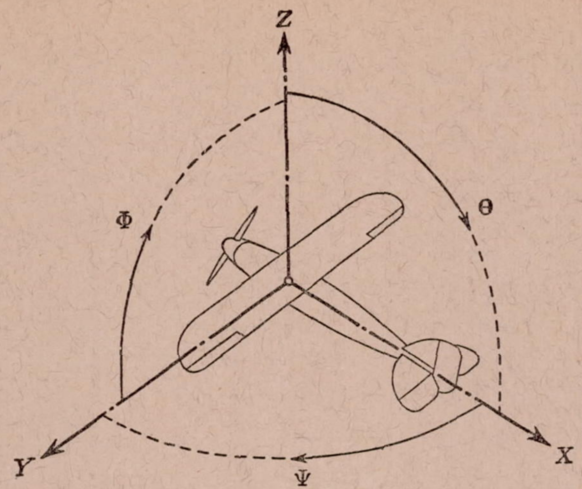
[1] Cowling No. 7 without vents.

TABLE II

PERFORMANCE MEASUREMENTS ON A WRIGHT J-5 ENGINE WITH DIFFERENT COWLINGS

	Reading No.	Air speed, m. p. h.	Engine speed, r. p. m	Brake horsepower	Fuel consumption, pounds per brake horsepower per hour	Barometer, inches of Hg.	Carburetor air temperature, °F.	Oil-in temperature, °F.	Oil-out temperature, °F.	Air-stream temperature, °F.
Cowling No. 4	1	81.4	1,705	170.5	0.677	29.90	76	129	129	82.2
	2	81.7	1,700	169.0	.696	29.90	75	133	133	82.8
	3	81.2	1,690	166.2	.681	29.90	76	139	138	83.5
	4	81.0	1,685	164.9	.720	29.91	76	145	143	84.2
	5	101.8	1,815	183.4	.648	29.80	88	151	149	86.0
	6	102.2	1,810	182.7	.651	29.80	88	151	151	87.0
	7	102.2	1,810	183.8	.650	29.80	90	153	152	87.8
	8	102.3	1,800	181.3	.669	29.80	94	158	156	88.2
	9	63.8	1,605	150.0	.748	30.00	78	158	156	88.0
	10	59.8	1,590	148.3	.749	30.00	77	158	157	87.8
	11	60.6	1,580	147.0	.749	30.00	77	161	160	87.8
	12	60.7	1,580	147.0	.749	30.00	77	166	163	87.8
Cowling No. 5	1	79.8	1,690	173.2	.686	30.25	----------	126	124	80.6
	2	80.6	1,645	158.8	.733	30.05	----------	134	132	80.6
	3	81.0	1,640	155.7	.727	30.05	----------	139	138	84.2
	4	81.0	1,640	155.7	----------	30.05	----------	144	143	84.2
	5	103.1	1,795	179.5	.661	29.97	----------	150	146	86.0
	6	103.0	1,790	176.3	.674	29.97	----------	153	151	86.0
	7	102.6	1,790	175.7	.644	29.97	----------	----------	----------	87.8
	8	102.6	1,780	172.3	----------	29.97	----------	----------	----------	87.8
	9	65.5	1,625	159.7	----------	30.13	----------	153	153	87.8
	10	61.8	1,560	141.8	----------	30.17	----------	163	158	87.8
	11	63.8	1,560	141.8	----------	30.17	----------	155	153	87.8
Cowling No. 7	1	80.6	1,700	175.7	.690	30.13	74	118	122	80.6
	2	80.7	1,650	159.4	.710	30.13	74	135	136	82.4
	3	80.3	1,625	154.8	----------	30.13	74	144	145	82.4
	4	104.0	1,805	186.4	.650	30.01	84	150	151	84.2
	5	104.3	1,790	177.3	.646	30.01	85	150	152	86.0
	6	103.7	1,760	169.4	----------	30.01	87	154	155	86.0
	7	64.0	1,680	181.5	.635	30.20	80	150	148	86.0
	8	62.0	1,590	153.5	.730	30.20	77	150	150	86.0
	9	62.5	1,560	144.4	----------	30.20	77	156	158	86.0
Cowling No. 10	1	85.1	1,730	183.9	----------	29.92	84	123	125	87.8
	2	84.3	1,675	159.2	.704	29.92	82	132	133	87.8
	3	63.6	1,700	187.0	.635	29.80	72	----------	142	78.8
	4	66.5	1,620	158.9	.699	29.80	69	----------	145	78.8
	5	63.2	1,580	141.0	----------	29.80	69	----------	148	78.8
	6	105.4	1,840	197.0	.616	29.60	80	----------	153	80.6
	7	104.6	1,790	177.9	.655	29.60	78	----------	153	80.6
	8	104.5	1,760	169.0	.665	29.61	77	----------	157	82.4

U. S. GOVERNMENT PRINTING OFFICE: 1929



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS} \qquad C_M=\frac{M}{qcS} \qquad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch.
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\ V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute, r. p. m.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft
1 m = 3.2808333 ft.