

**NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS**

REPORT No. 771

**REVIEW OF FLIGHT TESTS OF NACA C AND D
COWLINGS ON THE XP-42 AIRPLANE**

By J. FORD JOHNSTON



1943

AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbrevia- tion	Unit	Abbrevia- tion
Length.....	<i>l</i>	meter.....	m	foot (or mile).....	ft (or mi)
Time.....	<i>t</i>	second.....	s	second (or hour).....	sec (or hr)
Force.....	<i>F</i>	weight of 1 kilogram.....	kg	weight of 1 pound.....	lb
Power.....	<i>P</i>	horsepower (metric).....		horsepower.....	hp
Speed.....	<i>V</i>	(kilometers per hour.....	kph	miles per hour.....	mph
		meters per second.....	mps	feet per second.....	fps

2. GENERAL SYMBOLS

<p><i>W</i> Weight = mg</p> <p><i>g</i> Standard acceleration of gravity = 9.80665 m/s^2 or 32.1740 ft/sec^2</p> <p><i>m</i> Mass = $\frac{W}{g}$</p> <p><i>I</i> Moment of inertia = mk^2. (Indicate axis of radius of gyration k by proper subscript.)</p> <p>μ Coefficient of viscosity</p>	<p>ν Kinematic viscosity</p> <p>ρ Density (mass per unit volume)</p> <p>Standard density of dry air, $0.12497 \text{ kg-m}^{-4}\text{-s}^2$ at 15° C and 760 mm; or $0.002378 \text{ lb-ft}^{-4} \text{ sec}^2$</p> <p>Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb/cu ft</p>
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3. AERODYNAMIC SYMBOLS

<p><i>S</i> Area</p> <p><i>S_w</i> Area of wing</p> <p><i>G</i> Gap</p> <p><i>b</i> Span</p> <p><i>c</i> Chord</p> <p><i>A</i> Aspect ratio, $\frac{b^2}{S}$</p> <p><i>V</i> True air speed</p> <p><i>q</i> Dynamic pressure, $\frac{1}{2}\rho V^2$</p> <p><i>L</i> Lift, absolute coefficient $C_L = \frac{L}{qS}$</p> <p><i>D</i> Drag, absolute coefficient $C_D = \frac{D}{qS}$</p> <p><i>D₀</i> Profile drag, absolute coefficient $C_{D0} = \frac{D_0}{qS}$</p> <p><i>D_i</i> Induced drag, absolute coefficient $C_{Di} = \frac{D_i}{qS}$</p> <p><i>D_p</i> Parasite drag, absolute coefficient $C_{Dp} = \frac{D_p}{qS}$</p> <p><i>C</i> Cross-wind force, absolute coefficient $C_c = \frac{C}{qS}$</p>	<p><i>i_w</i> Angle of setting of wings (relative to thrust line)</p> <p><i>i_t</i> Angle of stabilizer setting (relative to thrust line)</p> <p><i>Q</i> Resultant moment</p> <p>Ω Resultant angular velocity</p> <p><i>R</i> Reynolds number, $\rho \frac{Vl}{\mu}$ where l is a linear dimen- sion (e.g., for an airfoil of 1.0 ft chord, 100 mph, standard pressure at 15° C, the corresponding Reynolds number is 935,400; or for an airfoil of 1.0 m chord, 100 mps, the corresponding Reynolds number is 6,865,000)</p> <p>α Angle of attack</p> <p>ϵ Angle of downwash</p> <p>α_0 Angle of attack, infinite aspect ratio</p> <p>α_i Angle of attack, induced</p> <p>α_a Angle of attack, absolute (measured from zero- lift position)</p> <p>γ Flight-path angle</p>
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Langley Field, Va.

National Advisory Committee for Aeronautics

Headquarters, 1500 New Hampshire Avenue NW., Washington 25, D. C.

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SUMMARY

Results of flight tests of the performance and cooling characteristics of three NACA D cowlings and of a conventional NACA C cowling on the XP-42 airplane are summarized and compared. The D cowling is, in general, characterized by the use of an annular inlet and diffuser section for the engine-cooling air.

The D cowlings tested were a long-nose high-inlet-velocity cowling, a short-nose high-inlet-velocity cowling, and a short-nose low-inlet-velocity cowling.

Increases of the maximum speed were obtained by use of the D cowlings as compared with the conventional C cowling arrangement. The increases corresponded to an over-all drag-coefficient reduction of 5 percent with the long-nose cowling and the short-nose low-inlet-velocity cowling, and 2 percent with the short-nose high-inlet-velocity cowling.

Small increases of the cooling pressure recovery in the full-power climb condition were also obtained by the long-nose high-inlet-velocity and the short-nose low-inlet-velocity cowlings, but the pressure recovery with the short-nose high-inlet-velocity cowling was less than that with the C cowling.

The use of wide-chord propeller cuffs or an axial-flow fan with the D cowlings increased the cooling pressure recoveries in the climb condition at the expense of some of the improvement in speed.

INTRODUCTION

In an extensive investigation directed toward improvement of radial-engine cowlings, the National Advisory Committee for Aeronautics has developed the type D cowling, characterized by the use of an annular inlet and diffuser section for the engine-cooling air. The development of what was considered the optimum NACA D cowling is described in reference 1. This long-nose cowling was built for the XP-42 airplane, which originally had a Pratt & Whitney R-1830-31 engine with an extended propeller shaft placing the propeller about 20 inches ahead of the normal position. Further wind-tunnel investigations, as described in reference 2, were directed toward adapting the NACA D cowling to the standard short-nose engine and again used the XP-42 airplane as a model.

The principal objectives of the wind-tunnel investigations were (1) reduction of external drag and increase of critical Mach number by smoothing the external flow and reducing the negative pressure peak and (2) reduction of cooling drag by increasing the cooling-air pressure recovery.

The three principal variations of the NACA D cowling, which resulted from these investigations, were a long-nose

high-inlet-velocity cowling, a short-nose high-inlet-velocity cowling, and a short-nose low-inlet-velocity cowling originally designed for use with a spinner-mounted axial-flow fan. These cowlings were then built for flight investigation of their performance and cooling characteristics on the XP-42 airplane. Tests of a conventional NACA C cowling on the same airplane were also carried out for purposes of comparison. Table I lists the various cowlings investigated and the modifications of auxiliary apparatus (propeller cuffs and/or fan) tested on each. The results of these flight tests were reported as soon as possible after the completion of each series and are contained in references 3 to 8. The present paper comprises a summary of these results and a comparison of the drag and cooling characteristics of the cowling arrangements investigated.


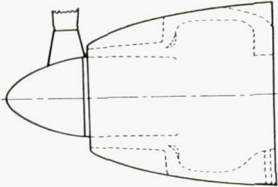
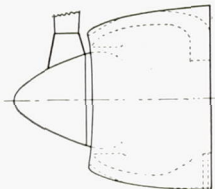
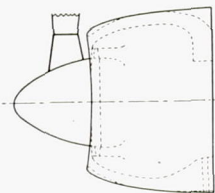
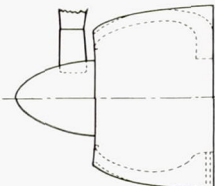
The design of the cowlings and engine installations was a project of the Air-Cooled Engine Installation Group stationed at the Langley Laboratory. The members of the group associated with this project included Mr. Howard S. Ditsch, of the Curtiss-Wright Corp.; Mr. Peter Torracco, of the Republic Aviation Corp.; Mr. William S. Richards, of the Wright Aeronautical Corp.; and Mr. James R. Thompson, of Pratt & Whitney Aircraft. The Army Air Forces, Matériel Command, sponsored the investigation and supplied the XP-42 airplane. The Curtiss-Wright Corp., Airplane Division, handled the construction as well as the structural and detail design of the cowlings and supplied personnel to assist in the servicing and maintenance of the airplane and cowlings during the tests. Pratt & Whitney Aircraft prepared the engine and torque meters for the tests and assisted in the operation and servicing of the engine. The propellers, cuffs, and spinners were supplied by the Curtiss-Wright Corp., Propeller Division.

The flight tests were conducted at Langley Field, Va., from May 1941 to December 1942.

DESIGNATIONS OF NACA D COWLINGS

Basic cowling designations have been defined in reference 2, in which the NACA D cowling designations listed were D_l , D_s , and D_{sf} . The subscripts l and s refer to designs suitable for long-nose and short-nose engines, respectively, and f indicates the use of a fan at the cowling entrance. For convenience in differentiating between the two short-nose D cowlings, numerical subscripts will be used in this report to designate the design inlet-velocity ratio. Thus $D_{s_{0.5}}$ refers to the short-nose high-inlet-velocity cowling which was designed for an inlet-velocity ratio of 0.5, and $D_{s_{0.3}}$ refers to the short-nose low-inlet-velocity cowling which was designed for an inlet-velocity ratio of 0.3.

TABLE I.—COWLINGS TESTED ON XP-42 AIRPLANE

Configuration 	Cowling designation	Test number		Accessories	Maximum speed at 1,000 horsepower at 14,500 feet (mph) ^a	Cooling-air pressure recovery, p/q_c		
		High speed	Climb			At high speed	In climb	
							At 140 mph indicated airspeed	At 155 mph indicated airspeed
	D ₁	1	2	Cuffs A.....	344	0.83	0.86	0.83
	D _{0.5}	3	16	Cuffs B.....	339	.80	.70	.70
		16B	16A	None.....	340	.74	.62	.62
	D _{0.3}	4	5	Fan, cuffs 1.....	338	.87	1.02	.95
		6						
		8	9	Fan only.....	340	.84	.98	.95
		11	10	None.....	344	.76	.74	.75
		12	13	Cuffs 1 only.....	340	.80	.86	.81
		15	14	Cuffs 2 only.....	343	.77	.84	.82
	C	18	17	Spinner and cuffs....	339	.69	.58	.58
		19	20	Cuffs only.....	338	.74	.68	.69
		22	21	None.....	338	.74	.67	.68

^a With cooling-air pressure drop of 16 inches of water.

SYMBOLS

- D maximum diameter of basic cowling
 X cowling length from lip to maximum diameter
 d cowling inlet diameter
 x abscissa of point on cowling measured from cowling lip parallel to thrust line
 y ordinate of point on cowling measured from point where tangent to cowling lip is perpendicular to thrust line
 Y value of y when $x=X$
 q_c airplane impact pressure, inches of water
 p pressure above free-stream static pressure, inches of water

APPARATUS AND METHOD

XP-42 AIRPLANE

The XP-42 airplane as tested was a P-36 airplane with the exception of the engine installation and the fuselage side

fairings behind the cowling. The engine was a 14-cylinder twin-row Pratt & Whitney R-1830-31, incorporating an extended nose section which placed the propeller about 20 inches ahead of the normal position. This extension was replaced by a standard nose for the tests with the short-nose D and C cowlings. The power rating of the engine was as follows:

Power condition	Brake horsepower	Engine speed (rpm)	Altitude (ft)
Take-off.....	1,050	2,550	0
Normal rating.....	1,000	2,300	8,500
Normal rating.....	1,000	2,450	11,500
Military rating.....	1,000	2,700	14,500

The engine had a single-stage blower with an impeller drive ratio of 8.47:1 and a propeller drive ratio of 9:16. A special set of cylinder baffles, designed to minimize the leakage of air between adjoining baffles and to fit more closely to the fins, was provided by the engine manufacturer.

Individual-cylinder exhaust jet stacks, designed according to reference 9, were used in place of the standard collector ring. The cross-section at the exhaust port was about 4.05 square inches, and the nozzle area at the end averaged about 2.98 square inches.

The airplane, as prepared for the tests, weighed 6000 pounds with pilot and full tanks; it retained the standard aerial but had no provisions for guns.

COWLINGS

Dimensioned drawings of each cowling are shown in figures 1 to 4. The ordinates of the forward parts of NACA cowlings D_1 and D_s are given in references 1 and 2, respectively. Ordinates for NACA cowling C are given in reference 10. The top and bottom of the D cowlings were altered to accommodate the charge and oil-cooling air ducts, but the sides have the basic cowling shape. Although these cowlings were developed independently to have smooth flat pressure distributions and high critical Mach numbers, it is interesting to note that the basic ordinates when plotted in terms of the ratios x/X and y/Y agree within the probable error of determination. These nondimensional ordinates for NACA cowlings D_1 and D_s are as follows:

x/X	y/Y	x/X	y/Y	x/X	y/Y
0	0	0.100	0.321	0.450	0.769
.005	.055	.150	.412	.500	.804
.010	.087	.200	.492	.600	.868
.020	.127	.250	.562	.700	.918
.030	.157	.300	.623	.800	.958
.050	.211	.350	.676	.900	.985
.075	.269	.400	.726	1.000	1.000

It is reasonable to suppose that cowlings intermediate to these two in dimensions would also have smooth pressure distributions and high critical Mach numbers at the appropriate inlet-velocity ratios. From reference 1, the critical Mach number of NACA cowling D_1 was about 0.74 for inlet-

velocity ratios as low as 0.32; and from reference 2, the critical Mach number of NACA cowling D_s was about 0.70 for inlet-velocity ratios at least as low as 0.47. The higher critical Mach number of cowling D_1 is probably due to its greater length. The proportions of the cowlings flight tested were as follows:

Cowling designation	Length X/D	Inlet diameter, d/D
D_1	0.63	0.64
D_s	.43	.71
C	.43	.65

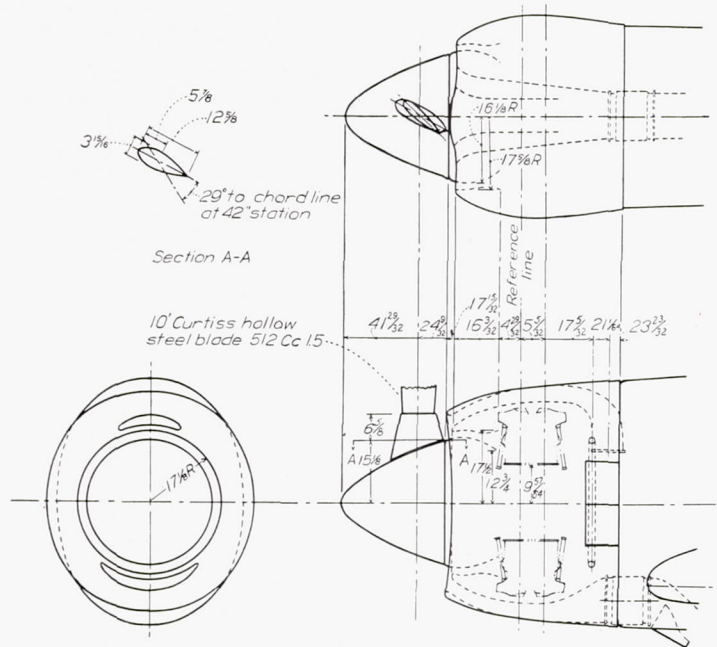


FIGURE 2.—Short-nose high-inlet-velocity cowling. (All dimensions are in inches.)

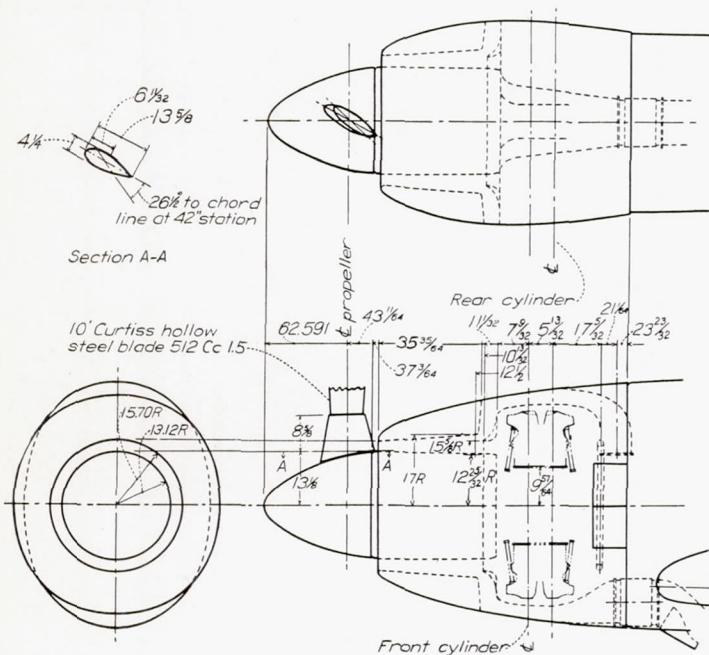


FIGURE 1.—Long-nose high-inlet-velocity cowling. (All dimensions are in inches.)

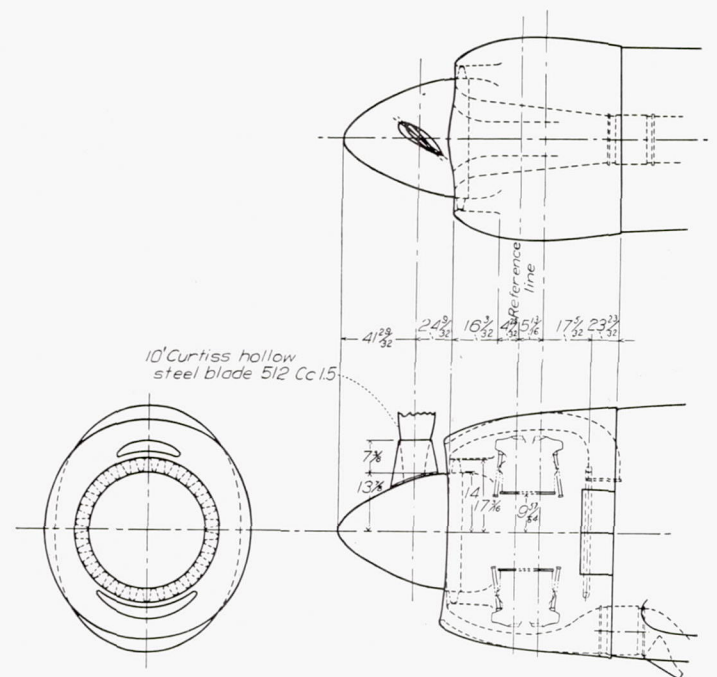


FIGURE 3.—Short-nose low-inlet-velocity cowling with axial-flow fan. (All dimensions are in inches.)

The long-nose cowling (fig. 1) was designed to induct the engine-cooling, carburetor, and oil-cooling air through the single annular inlet at about one-half the airplane velocity in the high-speed condition; that is, the design inlet-velocity ratio was 0.5. The supplies of carburetor and oil-cooling air were divided off by a "splitter ring" in the low-velocity region at the end of the diffuser section. The sections of the wide-chord propeller cuffs were symmetrical at the root, as shown in figure 1, and were tapered to conform with the propeller section at about the 22-inch radius. Views of the cowling as installed on the airplane are shown in figure 5.

The short-nose high-inlet-velocity cowling $D_{80.5}$, figures 2 and 6, had separate external scoops at the cowling lip for the induction and oil-cooling air. The annular inlet for the engine-cooling air, designed for an inlet-velocity ratio of 0.5 in the high-speed condition, was located at as large a radius as possible to aid the ground cooling. In order to reduce the thickness of the boundary layer in relation to the resultant narrow inlet gap, the spinner was reflexed slightly near the trailing edge, as may be seen in figure 6. The propeller cuff sections were symmetrical at the root, as shown in figure 2, and were tapered to conform with the propeller section at about the 22-inch radius.

The short-nose low-inlet-velocity cowling $D_{80.3}$, figures 3 and 7, had the same external cowling as the $D_{80.5}$. The design inlet-velocity ratio was reduced to 0.3 by the use of a smaller nonreflexed spinner, which increased the inlet area, and a new afterbody and cowling inner liner. Both sets of cuffs differed from the previous sets in that the camber line of the root section was reflexed from about the midchord point. Details of the spinner-mounted fan and of the cuffs are contained in references 5 and 6, respectively.

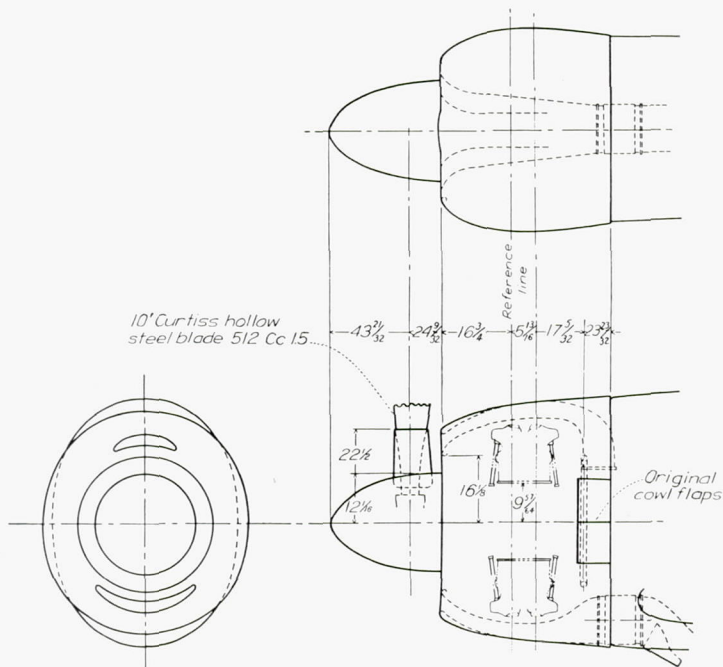
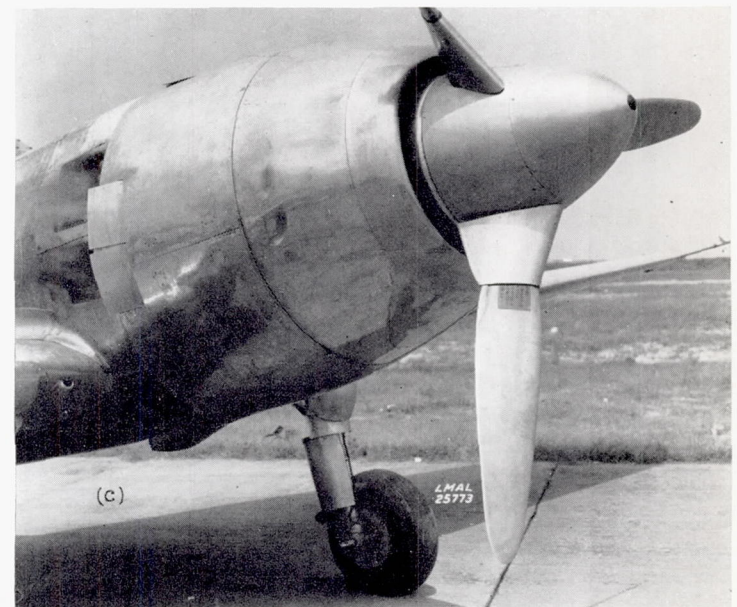
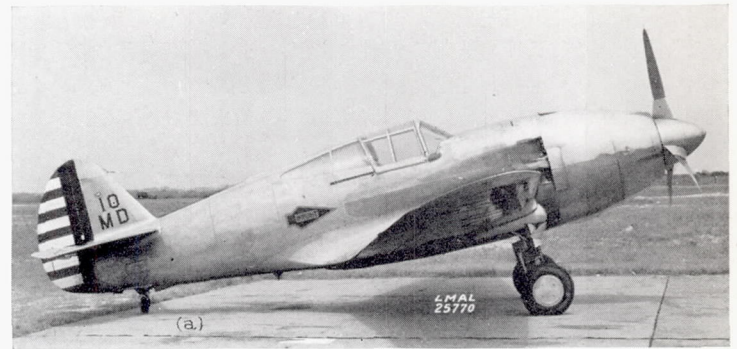
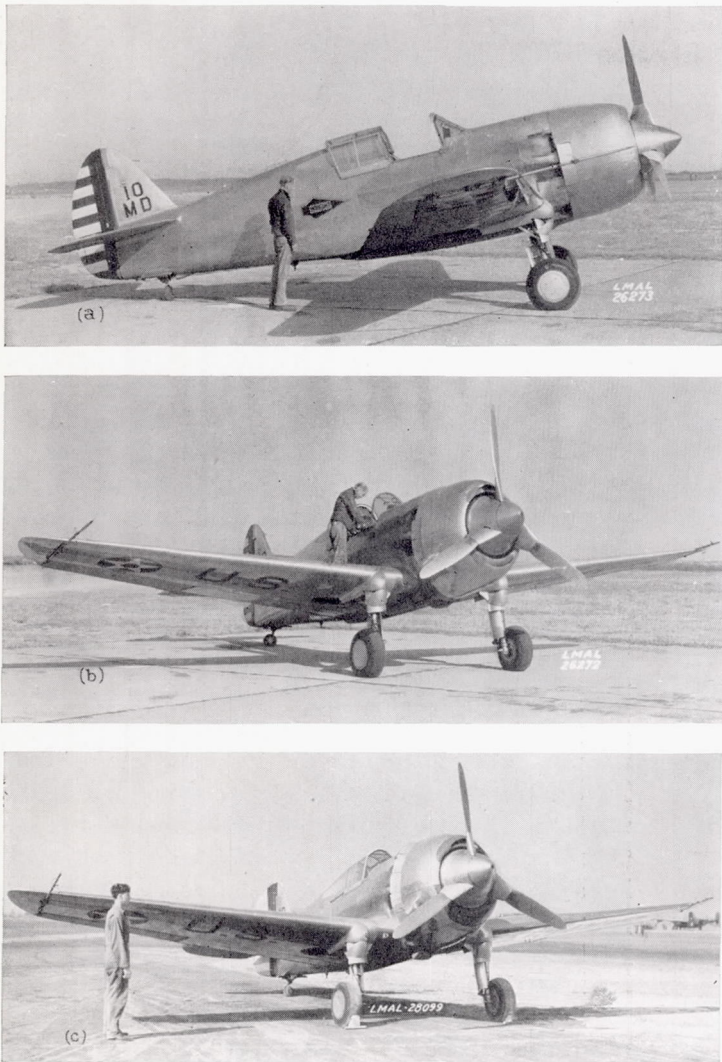


FIGURE 4.—NACA C cowling. (All dimensions are in inches.)



(a) Side view.
(b) Three-quarter front view.
(c) Close-up view.
(d) Three-quarter rear view showing modified cowling flaps.

FIGURE 5.—NACA D_1 cowling on XP-42 airplane.



(a) Side view.
 (b) Three-quarter front view.
 (c) Three-quarter front view showing modified cowl flaps.

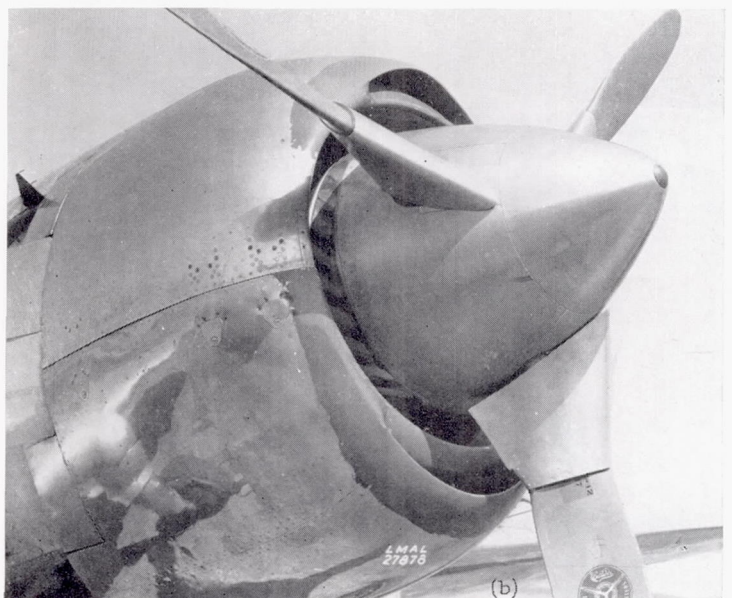
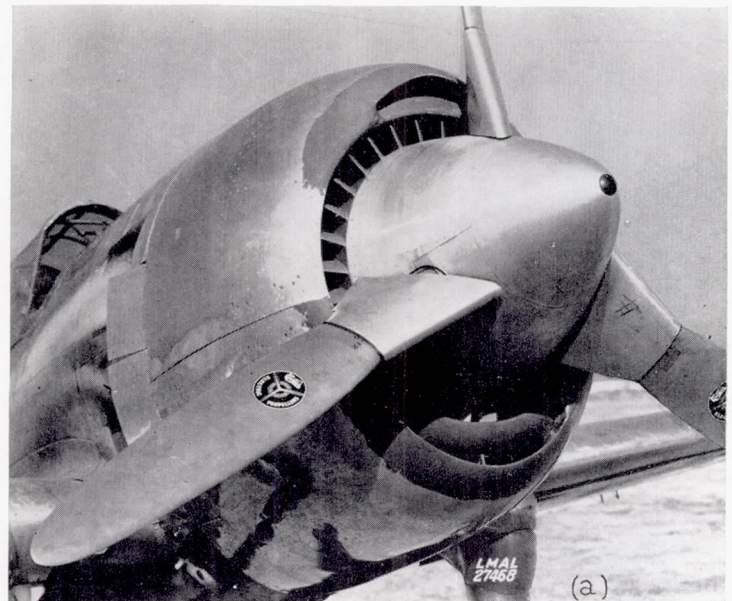
FIGURE 6.—NACA $D_{0.5}$ cowling on XP-42 airplane.

The NACA C cowling, shown in figures 4 and 8, was made from NACA cowling D_s . The narrow-chord cuffs and 24-inch-diameter spinner were of standard commercial manufacture for the propeller used.

The small cowl flaps originally provided for the airplane, shown in figures 1 to 5, proved inadequate for the climb tests, and three additional cowl flaps were installed on each side. The modified cowl flaps are shown in figures 5 (d) and 6 (c). The position of the extra cowl flaps could be changed only on the ground. For the high-speed tests they were fixed closed, and for the climb and ground-cooling tests they were fixed full open (approximately 35°). Some flexibility and lost motion existed in the supporting mechanism but the cowl-flap openings were not recorded in flight.

TEST EQUIPMENT

The test equipment used during the investigation is described in references 3 and 4. The quantities measured by the recording instruments included an extensive survey of the engine-cooling, carburetor, and oil-cooling air pressures; all cylinder-head and barrel-flange temperatures, along with



(a) With fan and cuffs 1.
 (b) With cuffs 2, without fan.

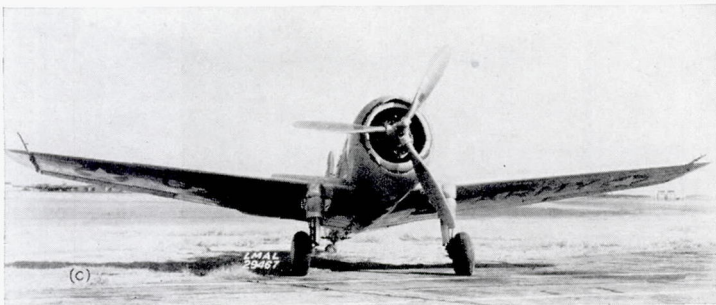
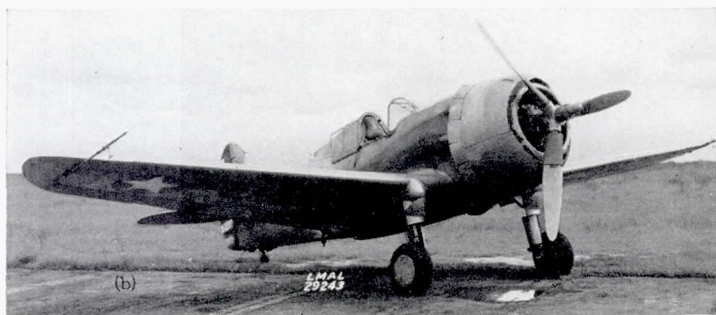
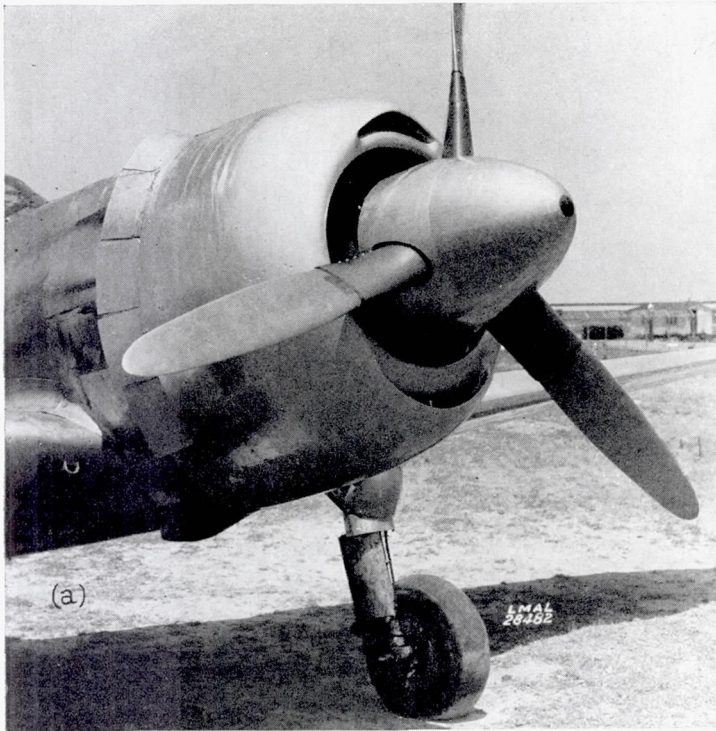
FIGURE 7.—NACA $D_{0.3}$ cowling on XP-42 airplane.

certain engine-accessory and air temperatures; the engine power and manifold pressure; and the airspeed and altitude.

HIGH-SPEED TESTS

The high speed was determined in each case by making a series of about 10 level runs at full throttle, 2700 rpm, at and above the engine critical altitude (from 14,500 to 19,000 ft). The cowl flaps were closed, carburetor heat off, and mixture control in automatic rich. All quantities were measured after stabilization in the run.

High-speed tests 1, 3, and 4 (table I) were made with the original small cowl flaps and the later tests, with the modified cowl flaps. Comparison of the results of test 4 with those of test 6 showed that the modified cowl flaps caused a speed loss of 2 miles per hour. This loss is attributed to air leakage around the modified flaps and would not be present in a well-designed cowl-flap installation. In order to keep the



- (a) With spinner and cuffs.
 (b) With cuffs, without spinner.
 (c) Without cuffs or spinner.

FIGURE 8.—NACA C cowling on XP-42 airplane.

results of all the cowling tests on a comparable basis, therefore, the speeds observed in tests using the modified cowl flaps have been raised by 2 miles per hour for quotation in this report. The resulting speed is the same as that which would be obtained by correcting the airplane drag coefficient for the added cowl-flap drag.

CLIMB TESTS

Two sustained climbs to about 20,000 feet were generally made with each cowling arrangement. One was at 140

miles per hour indicated airspeed, full rich, 2550 rpm, with the manifold pressure kept at about 43 inches of mercury to 7000 feet—then 42 inches until the full-throttle position was reached. The other was at 155 miles per hour indicated airspeed, automatic rich, 2550 rpm, with the manifold pressure at about 40 inches of mercury to full throttle. The automatic-rich setting provides a mixture compensation for altitude which is bypassed in the full-rich setting.

GROUND COOLING

Ground-cooling tests were made by running the engine at 1380 rpm, for about 10 minutes, then idling 5 minutes and shutting off after clearing the plugs. Engine-cylinder, engine-accessory, and air temperatures were recorded during the running periods and for 10 minutes after the engine was stopped. The propeller was in low pitch, cowl flaps were full open, and the airplane was sidewise to the wind. The ground-cooling test of the long-nose cowling was made with only the original small cowl flaps; the modified cowl flaps were used in the ground tests of the other cowlings.

RESULTS AND DISCUSSION

The maximum speed at rated military power and altitude at a cooling-air pressure drop of 16 inches of water and the engine-cooling-air pressure recovery for each cowling arrangement are listed in table I. These values, the one relating to the cowling drag and the other to the relative engine cooling capacity, are considered the most important features of cowling performance. The pressure drop of 16 inches of water was the average for the high-speed tests. This cooling pressure overcooled the cylinder heads but provided marginal cooling with respect to Army requirements for the tightly baffled cylinder barrels. So far as could be determined, the cooling pressure drop required was independent of the type of cowling. More complete results are contained in references 3 to 8.

MAXIMUM SPEED

At the Mach number (about 0.45) at which the high-speed runs were made, the maximum difference in speed between the cowlings was about 2 percent of the maximum speed and corresponded to a 5-percent change in the airplane drag coefficient. From references 1, 2, and 10, the expected critical Mach number for NACA cowlings D_1 , $D_{0.5}$, and C were about 0.74, 0.70, and 0.63, respectively. The critical Mach number for NACA cowling $D_{0.3}$ was not measured. If the cowlings had been tested at higher Mach numbers, it is expected that the speed differences would amount to a larger proportion of the maximum speed.

The grouping according to speed was roughly the same as the grouping according to expected critical Mach number, with the exception that cowling $D_{0.3}$ without cuffs showed as high a speed as cowling D_1 . Unfortunately, the long-nose cowling was not tested without cuffs so that it is not known whether the cuffs decreased the maximum speed obtainable with this cowling.

Effect of ram on speed.—In the speed comparison of table I, made on the basis of operating at the rated military power and altitude, the carburetor ram was assumed to be zero; that is, the air density at the carburetor was assumed to be equal to the free-air density. Where ram is available, the accompanying density rise at the carburetor increases the altitude to which the rated power can be maintained and, therefore, increases the maximum speed obtainable. For the short-nose cowlings with the external scoop, the ram averaged $1.0q_c$; but the internal ducting arrangement of the long-nose cowling reduced the ram for that installation to $0.75q_c$. With the ram and the accompanying temperature rise in the carburetor duct due to the adiabatic compression and to heat absorption through the duct walls, the carburetor-air densities were about 5 percent above free-air density for the long-nose cowling and 8 percent for the short-nose cowlings. The corresponding increments of speed due to this increase of critical altitude would be about 5 miles per hour for cowling D_1 and 8 miles per hour (above the values quoted in table I) for the other cowlings. On this basis, cowling $D_{s_{0.3}}$ would show a higher speed than cowling D_1 even though its basic drag was about the same. The internal ducting of cowling D_1 must be improved before the external drag reduction can be fully exploited.

Effect of fan and cuffs on speed.—Table I shows that the fan tested with cowling $D_{s_{0.3}}$ reduced the top speed by approximately 4 miles per hour and increased the cooling pressure recovery at high speed by about $0.08q_c$. The pressure rise calculated from tests of similar fans (reference 11) was also $0.08q_c$. The calculated fan power absorption was about 15 horsepower, or the equivalent of a 2-mile-per-hour reduction in top speed. The difference between the calculated and measured speed losses is within the combined accuracy of measurement of the two speeds involved.

The wide-chord propeller cuffs tested with the D_s cowlings cost from 1 to 4 miles per hour in top speed and had varying effects upon the pressure recovery in the high-speed condition. In each case, however, they increased the pressure recovery in the full-power climb condition by about $0.1q_c$. It appears from these data that wide-chord propeller cuffs may be used for improving climb cooling which will have little or no effect upon the maximum speed but that the effect on the speed may be critically dependent on the cuff setting or shape.

In contrast to the wide-chord cuffs, the narrow-chord cuffs of cowling C had negligible effect upon the speed and the engine-cooling-air pressures in flight.

ENGINE-COOLING-AIR PRESSURES

The average cooling-air pressures on the front of the engine for each cowling arrangement are listed in table I.

Basic pressure recoveries.—Of the four cowlings, the $D_{s_{0.5}}$, $D_{s_{0.3}}$, and C were tested in the basic condition, that is, without fan or cuffs. The difference in pressure recovery between these basic cowlings was negligible in the high-speed condition, as is shown by the pressure recoveries of 74, 76,

and 74 percent of free-stream impact pressure. It is probable that cowling D_1 if tested without cuffs would have shown very nearly the same pressure recovery as the other cowlings.

In the 140-mile-per-hour climb condition, where the cooling is more critical, some difference appeared between the basic cowlings. The pressure recovery with cowling $D_{s_{0.5}}$ dropped from $0.74q_c$ in the high-speed condition to $0.62q_c$ in the climb condition; with cowling C, from $0.74q_c$ to $0.67q_c$; and with cowling $D_{s_{0.3}}$, from $0.76q_c$ to $0.74q_c$. Some decreased recovery is usually expected to accompany the increase in angle of attack. With cowling $D_{s_{0.5}}$, this loss was augmented by an increase of the inlet-velocity ratio to about 0.7, which was well beyond the optimum for the short length of diffuser available. With cowling $D_{s_{0.3}}$, on the other hand, the increase of inlet-velocity ratio to about 0.45 apparently improved the flow to offset the expected loss due to increased angle of attack.

Direct comparison of the pressure recovery in climb of cowling D_1 with that of the other cowlings is somewhat difficult because it was not tested without cuffs. When it is noted, however, that the other wide-chord cuffs gave pressure increments in the 140-mile-per-hour full-power climb condition that ranged only from $0.08q_c$ to $0.12q_c$, it then appears probable that the pressure recovery in climb with cowling D_1 without cuffs would correspondingly have been from $0.08q_c$ to $0.12q_c$ lower than that observed with the cuffs. The probable pressure recovery in climb of cowling D_1 without cuffs is then from $0.74q_c$ to $0.78q_c$. These figures compare favorably with the pressure recoveries observed with the other cowlings in the basic condition.

Although the comparison is favorable, it does not represent the full potentialities of the diffuser used with the long-nose cowling. The pressure recovery on the front of the engine was $0.12q_c$ less than the total pressure of the air in the low-velocity region at the end of the diffuser. This low-velocity air was forced to undergo a considerable velocity increment in passing through the "splitter ring," and failure to recover the kinetic energy so attained caused the quoted loss of $0.12q_c$. These considerations lead to the conclusion that a basic pressure recovery without cuffs of as high as $0.85q_c$ would probably be available in a similar long-nose cowling design which took full advantage of the diffuser.

Pressure recoveries with fan or cuffs.—Whereas the wide-chord cuffs raised the cooling pressure recoveries in climb by about $0.1q_c$, as has been noted, the fan with cowling $D_{s_{0.3}}$ raised the pressure recovery by about $0.25q_c$, or $2\frac{1}{2}$ inches of water. According to reference 11, some further increases may be obtained by using a fan of greater solidity or by using contravanes. If large increases of cooling pressure are required, however, the fan must be operated at higher speeds, that is, geared above propeller speed.

Pressure distribution around engine.—The observed distributions of cooling pressures around the engine are plotted in figures 9 and 10 for several cowling arrangements. The distributions in the high-speed condition, figure 9, were fairly uniform for all the cowlings, as would be expected. In the climb condition, the distributions were less uniform and there

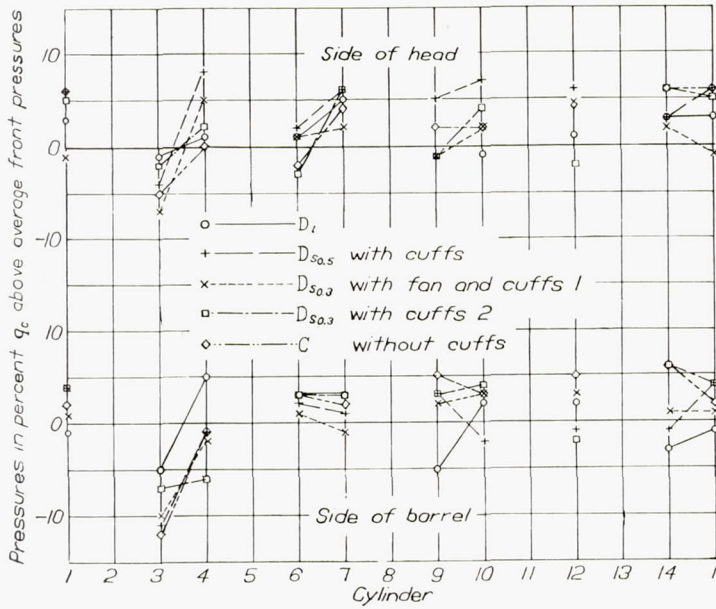


FIGURE 9.—Pressure distributions around engine in high-speed condition.

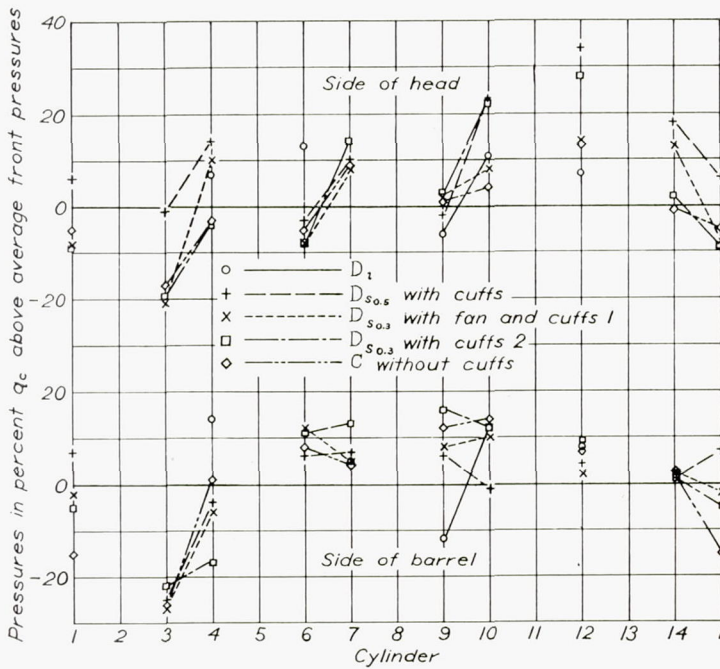


FIGURE 10.—Pressure distributions around engine in climb condition.

was a general tendency toward higher pressures at the bottom and lower left of the cowling. No significant differences between the cowlings are discernible from these figures although perhaps a more complete survey would have revealed them.

Radial distribution.—The radial pressure distributions for several cowling arrangements are plotted in figure 11 for the high-speed condition and in figure 12 for the climb condition. Each point through which a curve is drawn was averaged from measurements on four or five different cylinders, but the points shown at 1.2 inches from the cylinder base in figure 11 were measured only on cylinder 4 in the case of the front cylinders and only on cylinder 3 in the case of the rear cylinders. These points near the bottom of the cylinder are

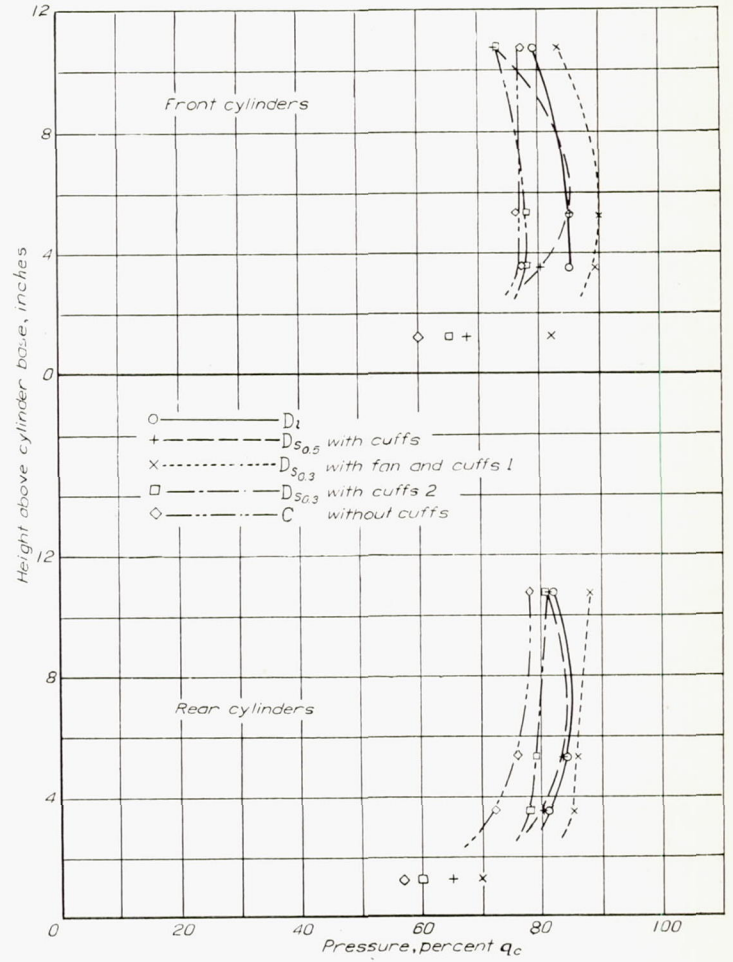


FIGURE 11.—Average radial pressure distributions in high-speed condition.

believed to be indicative of the trend of distribution but do not so closely represent the average distribution as do the other points. Figures 11 and 12 show the effect of the annular jet from the diffuser section upon the cooling pressures up and down the cylinder. The jet effect was confined principally to the front cylinders and was more pronounced in the climb condition. The high-inlet-velocity cowlings showed more effect than the low-inlet-velocity cowling, but with cowling D_1 the jet effect resulted from velocity acquired by the air in passing through the "splitter ring" rather than from the velocity remaining at the exit of the long diffuser passage. The jet localized the high-pressure region near the juncture of the cylinder head and barrel at the expense of the pressures at the ends of the cylinder. No apparent adverse effects upon the cylinder-head cooling resulted from this radial pressure distribution inasmuch as the jet was so placed as to cover the hottest parts of the cylinder and to supply high-pressure air at the base of the vertical head fins.

The deficiency of pressure near the base of the cylinders was found to be characteristic of the C cowling as well as of the D cowlings. Correspondingly, the barrel temperatures, measured at the rear center line of the flange at the base of the cylinder, were marginal or exceeded the Army limit in both the climb and high-speed conditions with all the cowlings tested.

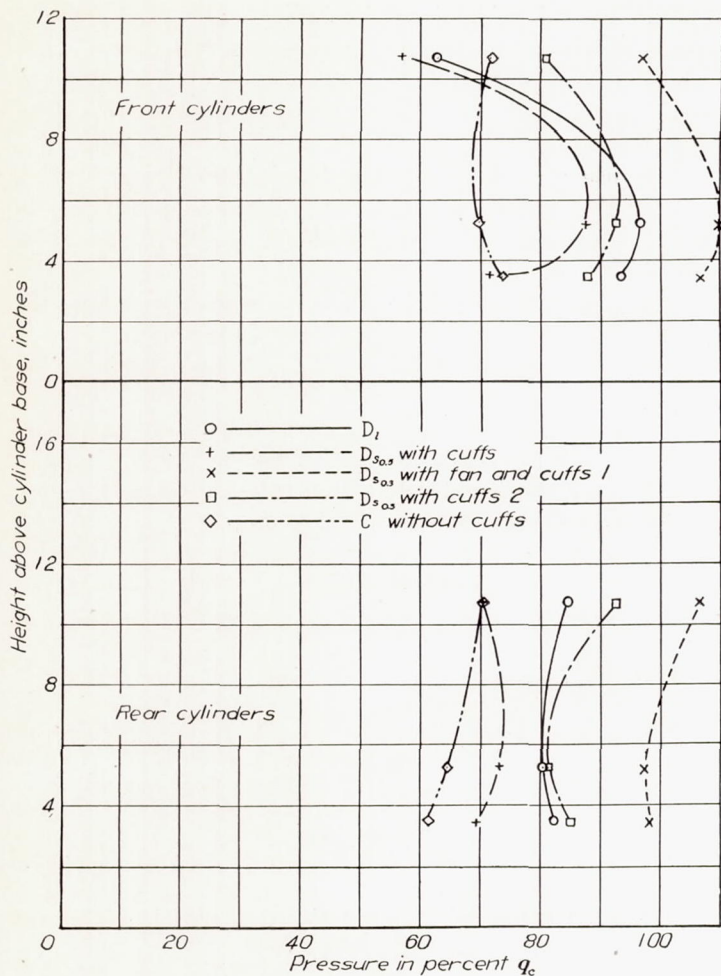


FIGURE 12.—Average radial pressure distributions in climb condition.

GROUND COOLING

Cylinder-head and barrel temperatures were found to be below their limits during all the ground-cooling runs. The critical items noted were generally the oil-in temperatures while the engine was running and the spark-plug-elbow temperatures after the engine was stopped. During preliminary tests the magneto temperatures were also critical until the accessory-compartment venting was improved. The use of propeller cuffs generally brought all temperatures below their Army limits.

Cooling with cuffs.—Time histories of the hottest cylinder-head and spark-plug-elbow temperatures observed during the ground-cooling runs of the four cowlings with cuffs are shown in figure 13. Similar plots for the $D_{s_{0.5}}$, $D_{s_{0.3}}$, and C cowlings without cuffs are shown in figure 14. In order to avoid confusion of curves and because the oil-cooling systems for the short-nose cowlings were identical, the oil-in temperatures are not included. The ground run with cowlings D_1 was made with only the original small cowl flaps, whereas the other ground runs were made with the modified cowl flaps. From figure 13, cowlings D_1 appears to have cooled as well as the other D cowlings. The oil-in temperature, however, just equalled its Army limit; whereas, for the

other cowlings with cuffs, it remained from 5° F to 10° F below the limit. The C cowlings with spinner and narrow-chord cuffs showed higher cylinder and elbow temperatures than did the D cowlings with wide-chord cuffs although it was the coolest of the C cowlings arrangements.

Cooling without cuffs.—In the runs without cuffs, figure 14, all temperatures were appreciably higher than in the runs with cuffs. With cowlings $D_{s_{0.5}}$, the engine was throttled back to idling after only 5 minutes at 1380 rpm because of excessive indicated oil-in temperatures. The tests with the $D_{s_{0.3}}$ and C cowlings without cuffs were continued in spite of oil temperatures about 20° F above the Army limit. Because of the similarity of the oil cooling systems, approximately the same oil temperatures might have been expected for cowlings $D_{s_{0.5}}$ if the run had not been shortened. The hottest spark-plug elbow with cowlings $D_{s_{0.5}}$ would also have been expected to reach a maximum comparable with that of cowlings $D_{s_{0.3}}$, or about 10° F above the Army limit (of 148° F above free-air temperature). With cowlings C, the hottest spark-plug elbow reached a maximum about 60° F above the Army limit. In each case, the maximum spark-plug-elbow temperatures were obtained after the engine was stopped.

The results of these ground runs indicate that ground cooling is no more difficult with the D cowlings than with the conventional C cowlings.

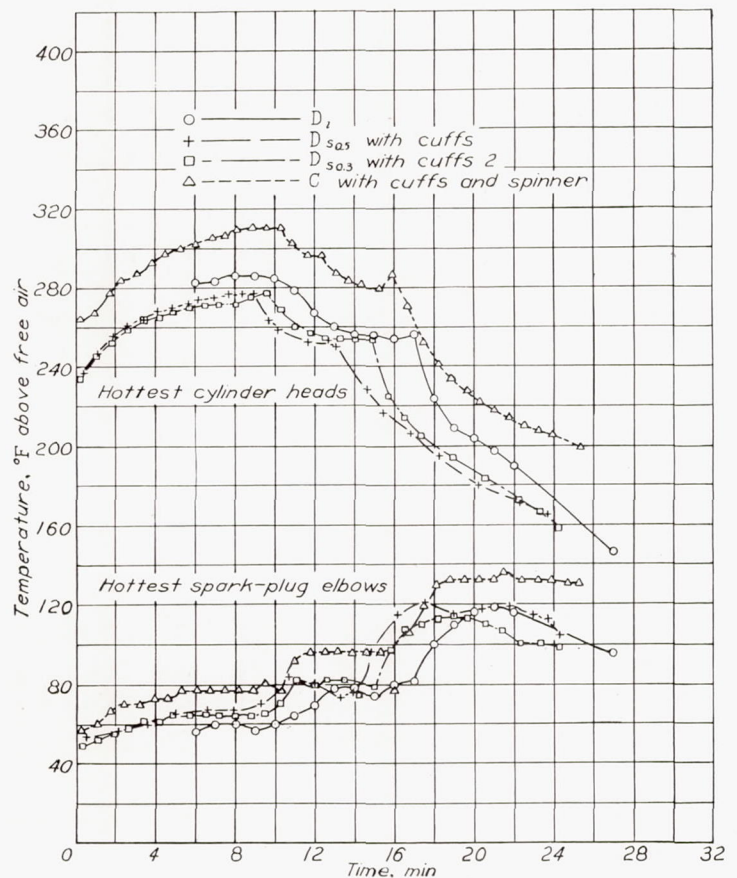


FIGURE 13.—Temperatures during ground-cooling tests of cowlings with cuffs.

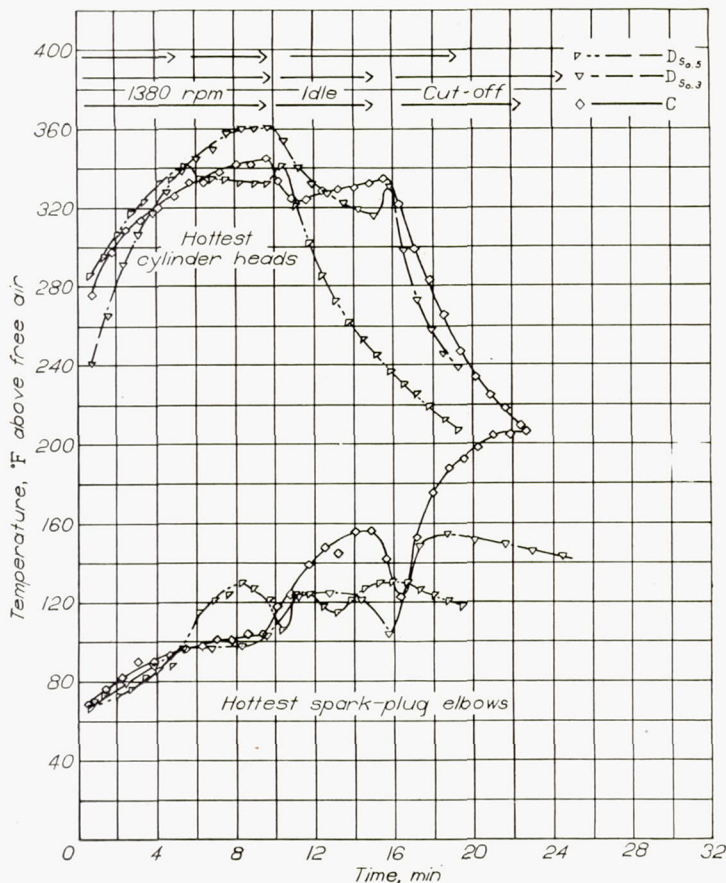


FIGURE 14.—Temperatures during ground-cooling tests of cowlings without cuffs.

CONCLUSIONS

Flight tests of the XP-42 airplane equipped successively with an NACA D_t , $D_{s_{0.5}}$, $D_{s_{0.3}}$, and C cowling indicated the following conclusions:

1. The maximum speed was increased by a change from a C cowling to a D cowling by an amount corresponding to an airplane drag-coefficient reduction of 5 percent with the long-nose high-inlet-velocity cowling and the short-nose low-inlet-velocity cowling, and 2 percent with the short-nose high-inlet-velocity cowling.

2. The engine-cooling-air pressure recovery was also increased by the change so long as the inlet velocity was not too high for the diffuser used. The pressure recovery in the full-power climb condition was increased by about 7 percent of airplane impact pressure ($0.07q_c$) by the short-nose low-inlet-velocity cowling, but it was decreased by about 5 percent q_c by the short-nose high-inlet-velocity cowling. Although direct comparative tests were not made, it was deduced that the long-nose high-inlet-velocity cowling, modified internally, might be capable of increasing the pressure recovery in climb by about 18 percent q_c as compared with the C cowling.

3. The use of wide-chord propeller cuffs with the D cowlings increased the pressure recovery in full-power climb by about 1 inch of water (10 percent q_c) and improved the ground cooling but decreased the top speed by from 1 to 4 miles per hour.

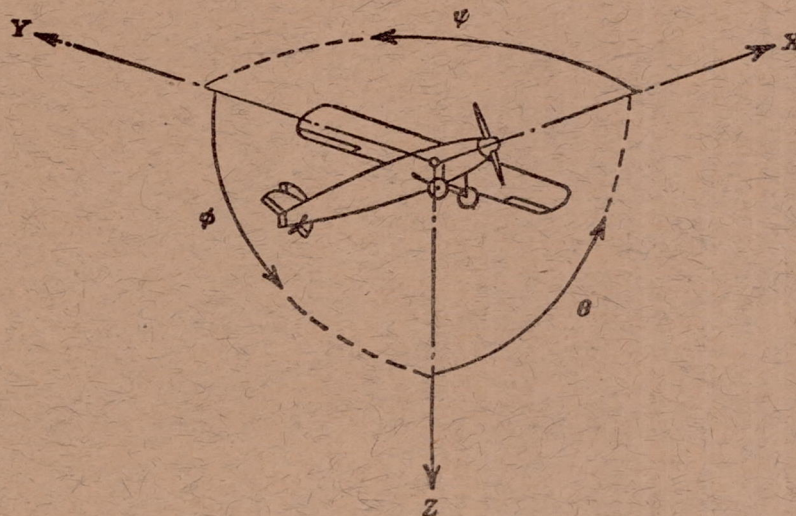
4. The use of a fan with the low-inlet-velocity cowling raised the pressure recovery in climb by about $2\frac{1}{2}$ inches of water (25 percent q_c) but decreased the top speed by 4 miles per hour.

5. The ground cooling with the D cowlings without cuffs compares favorably with that with the C cowling.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., April 20, 1943.

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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	Sym- bol		Designation	Sym- bol	Positive direction	Designa- tion	Sym- bol	Linear (compo- nent along axis)	Angular
Longitudinal.....	X	X	Rolling.....	L	Y→Z	Roll.....	φ	u	p
Lateral.....	Y	Y	Pitching.....	M	Z→X	Pitch.....	θ	v	q
Normal.....	Z	Z	Yawing.....	N	X→Y	Yaw.....	ψ	w	r

Absolute coefficients of moment

$$C_l = \frac{L}{qbS} \quad C_m = \frac{M}{qcS} \quad C_n = \frac{N}{qbS}$$

(rolling) (pitching) (yawing)

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

4. PROPELLER SYMBOLS

D	Diameter	P	Power, absolute coefficient $C_P = \frac{P}{\rho n^3 D^5}$
p	Geometric pitch	C_s	Speed-power coefficient $= \sqrt[5]{\frac{\rho V^5}{P n^2}}$
p/D	Pitch ratio	η	Efficiency
V'	Inflow velocity	n	Revolutions per second, rps
V_s	Slipstream velocity	Φ	Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi r n}\right)$
T	Thrust, absolute coefficient $C_T = \frac{T}{\rho n^2 D^4}$		
Q	Torque, absolute coefficient $C_Q = \frac{Q}{\rho n^2 D^5}$		

5. NUMERICAL RELATIONS

1 hp = 76.04 kg·m/s = 550 ft·lb/sec
 1 metric horsepower = 0.9863 hp
 1 mph = 0.4470 mps
 1 mps = 2.2369 mph

1 lb = 0.4536 kg
 1 kg = 2.2046 lb
 1 mi = 1,609.35 m = 5,280 ft
 1 m = 3.2808 ft