NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 414

THE EFFECT ON AIRPLANE PERFORMANCE OF THE FACTORS THAT MUST BE CONSIDERED IN APPLYING LOW-DRAG COWLING TO RADIAL ENGINES

By WILLIAM H. McAVOY, OSCAR W. SCHEY, and ALFRED W. YOUNG

1932

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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/h	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.

$\frac{b^2}{S}$, Aspect ratio.

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 $C_D = \frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o} = \frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i} = \frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$

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

R, Resultant force.

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

i_t, Angle of stabilizer setting (relative to thrust line).

Q, Resultant moment.

Ω, Resultant angular velocity.

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

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, at 15° C., the corresponding number is 234,000;

or for a model of 10 cm chord 40 m/s, the corresponding number is 274,000.

C_p, Center of pressure coefficient (ratio of distance of $c. p.$ from leading edge to chord length).

α, Angle of attack.

ϵ, Angle of downwash.

α_o, Angle of attack, infinite aspect ratio.

α_i, Angle of attack, induced.

α_a, Angle of attack, absolute. (Measured from zero lift position.)

γ Flight path angle.

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Langley Memorial Aeronautical Laboratory

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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. Its membership was increased to 15 by act approved March 2, 1929 (Public, No. 908, 70th Congress). It consists of members who are appointed by the President, all of whom serve as such without compensation.)

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SUMMARY

This report presents the results of flight tests with three different airplanes using several types of low-drag cowling for radial air-cooled engines. The greater part of the tests were made with a Curtiss "XF7C–1" ("Sea Hawk") with a 410-hp. Wasp engine, using three fuselage nose shapes and six types of outer cowling. The six cowlings were: A narrow ring, a wide ring, a wide cowling similar to the original N. A. C. A. cowling, a thick ring incorporating an exhaust collector, a single-surface cowling shaped like the outer surface of the exhaust-collector cowling, and a polygon-ring cowling, of which the angle of the straight sections with the thrust line could be varied over a wide range.

The high speed in level flight was determined by means of timed runs over a measured course. Ten-minute full-throttle climbs were made for several of the cowling conditions. Temperatures at 18 points on the engine cylinders were measured for a large number of climbs and level flights. Photographs showing the pilot's field of vision were taken for several cowling conditions.

The addition of outer cowlings to the "XF7C–1" resulted in speed increases of from 6 to 20 miles per hour, depending upon the type of cowling and the fuselage shape. The narrow-ring cowling gave the least increase in speed and the single-surface cowling the greatest. A reasonably wide cowling with its leading edge behind the front plane of the engine cylinders gave the best performance of the plain-ring types of cowling. The optimum range for the angle of the cowling section with the thrust line was only 3° or 4°; the position of the range was dependent upon the shape of the fuselage and the shape and location of the cowling section. In general the engine temperatures increased as the high speed was increased, both of these effects being directly contributed to by reductions in the amount of air flowing past the cylinders. The use of cowlings had very little effect upon the performance in climb.

Less extensive tests were made on a Vought "O2U–1" ("Corsair") and a Fairchild "FC2W–2" with some of the same cowlings used on the "XF7C–1." Only the high speed of these airplanes was determined, to furnish a check on the effect of cowlings with different types of airplanes.

INTRODUCTION

In 1928 the National Advisory Committee for Aeronautics conducted in its 20-foot propeller-research tunnel an investigation of cowlings for radial air-cooled engines. (References 1, 2, and 3.) This investigation showed that a remarkably large reduction in drag could be obtained by the use of a cowling which completely inclosed the engine and which admitted the cooling air through an opening in the front and discharged it through an annular opening at the rear of the engine. Tests on low-drag cowlings have also been conducted in England by the Aeronautical Research Committee. (Reference 4.) In these tests a ring was fitted over the engine cylinders to reduce the drag by decreasing both turbulence and the breakaway of the flow from the surface of the body behind the engine.

Since the foregoing tests were made the manufacturers of radial air-cooled engines have shown considerable interest in low-drag cowlings. Nearly every recent installation of large radial air-cooled engines includes some form of this type of cowling. Not all installations have been entirely successful, however, because many users have not appreciated the fact that the shape, the width, the location of the outer cowling with respect to the engine cylinders, the angle of attack of the cowling section with respect to the center line of the crankshaft, and the lines of the inner cowling are all very important and should be carefully considered for each installation.

A comprehensive investigation concerning the effect on performance of each of the above variables was conducted by the committee. Three different fuselage nose shapes were used on a Curtiss *XF7C–1* airplane. With each of these fuselage nose shapes several outer cowlings of different width, shape, location, and angle of attack were used. A few tests were also made using a Vought *O2U–1* and a Fairchild *FC2W–2* with some of the cowlings tested on the *XF7C–1*. The problem of vision was considered to the extent of taking pictures of the different cowling installations with the camera located at the pilot's position in the cockpit.

The object of this report is to correlate and present the flight-test data on low-drag engine cowlings that have so far been obtained by the committee. Some of the information has been previously published in the form of technical notes. (References 5 and 6.)

EQUIPMENT AND METHOD

"XF7C-1" AIRPLANE

The greater part of the flight research on the air-cooled engine cowlings was conducted on the Curtiss *XF7C-1* airplane. This airplane is a single-place shipboard fighter powered with a Pratt & Whitney Wasp engine rated at 410 hp. at 1,900 r. p. m. The original *XF7C-1* wings of 242-square-feet area had been replaced, after a crash, with *F7C-1* wings of 275-square-feet area. Figure 1 shows this airplane in its service condition.

An aluminum-alloy adjustable-blade propeller was used (Navy drawing No. 3792). The diameter of this propeller had been cut from 10 feet to 9 feet. Tests conducted on this propeller in the propeller-research tunnel had shown that reducing the diameter did not appreciably affect its maximum efficiency. (Reference 9.) The propeller pitch setting was changed as the cowlings were changed, in order to keep the maximum engine speed at approximately 1,950 r. p. m. in full-throttle level flight at sea level.

In this report the service fuselage is called "fuselage 1." The engine cowling of fuselage 1 is of conventional design, covering the cylinders and approximately one-half of the aluminum-alloy cylinder heads, and incorporating shutters in the nose. With the service fuselage and no outer cowling the weight of the airplane at take-off was 3,024 pounds. This included 165 pounds for the pilot with his equipment and 90 pounds for the flight-test instruments.

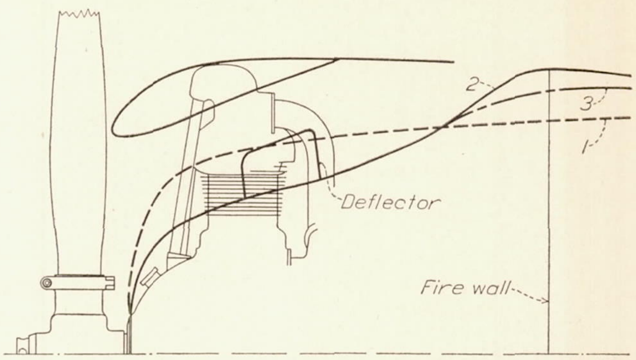


FIGURE 2.—The nose of the *XF7C-1* airplane for each of three fuselages tested, and location of cowling C with respect to the engine and to each fuselage nose

Two other fuselage nose shapes were used in conjunction with the series of outer cowlings. The shapes of the three fuselages are shown in the sketch on Figure 2. Fuselages 2 and 3 were intended to be used with an outer cowling. They are smaller in diameter at the nose than the service fuselage, allowing more of the cylinder finning to extend into the air stream. At the rear of the engine they swell out rapidly to a section somewhat larger than the original fuselage, and then are faired smoothly into the original fuselage. Fuselages 2 and 3 are alike except that fuselage 2 is slightly thicker and has a sharper curvature at the maximum section just behind the engine. The airplane weight at take-off with fuselages 2 and

FIGURE 1.—The *XF7C-1* airplane with fuselage 1 and no outer cowling

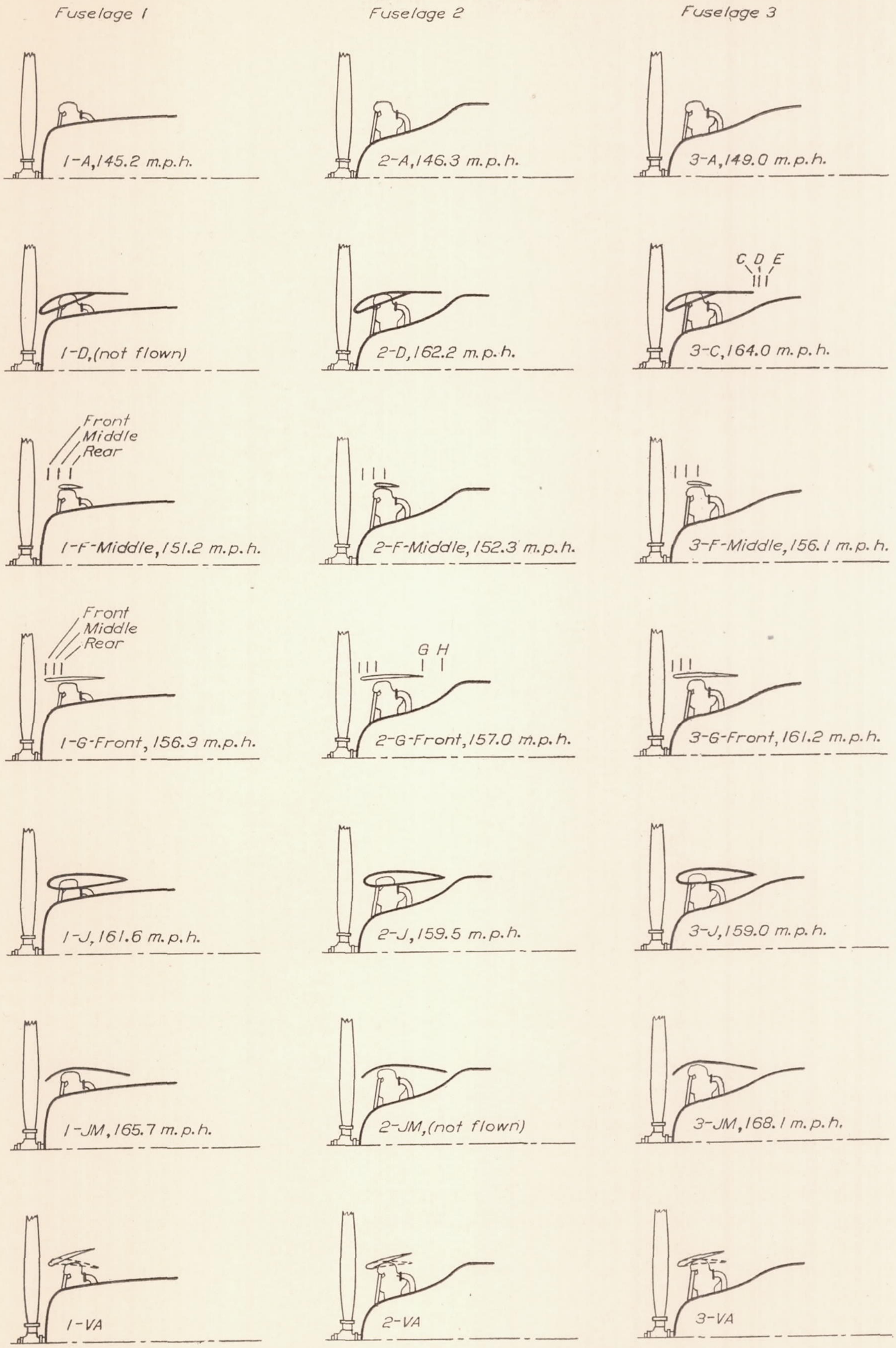


FIGURE 3.—Outer cowlings used with each of three fuselages on the *XF7C-1* airplane

3 without an outer cowling was 3,076 and 3,024 pounds respectively. The outer cowlings used are denoted by letters, as follows:

Cowling A.—The letter "A" has been used to denote the condition with no outer cowling.

Cowling D.—The length of the skirt of cowling C was increased 1½ inches to make cowling D.

Cowling E.—The length of the skirt of cowling D was increased 2½ inches to make cowling E.

FIGURE 4.—The *XF7C-1* airplane with cowling 3-D

Cowling C.—Cowling C (figs. 3 and 4) is similar to the ring of the No. 10 cowling described in references 1 and 3. A cross section of cowling C resembles a highly cambered airfoil section set at a large negative angle with the thrust line. The outer surface is continued back in cylindrical form to lead into the lines of the fuselage. Only a small slot is left between the skirt of the cowling and the fuselage for the exit of the cooling air. (Reference 7.) With its mounting brackets cowling C weighs 40 pounds.

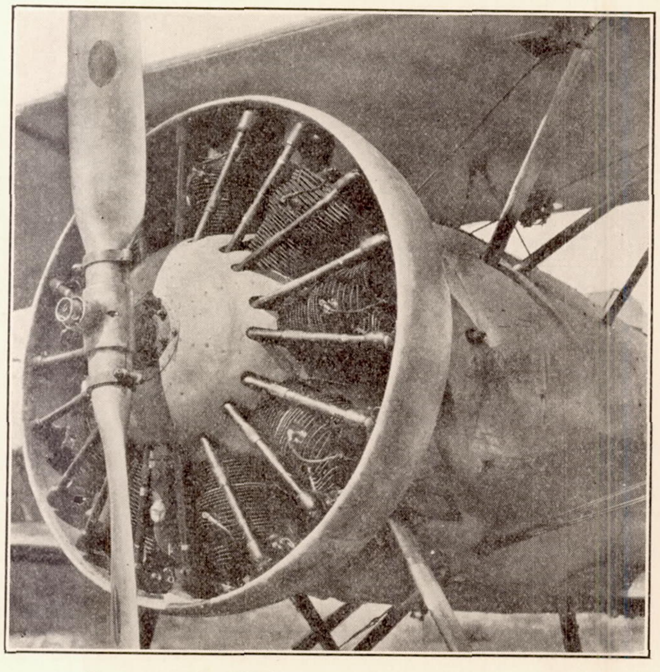


FIGURE 5.—The *XF7C-1* airplane with cowling 3-F-Middle

Cowling F.—Cowling F (figs. 3 and 5) is a ring 9 inches wide, having a Clark Y airfoil profile with its chord parallel to the thrust line. In its middle position (fig. 5) cowling F was located over the center line of the engine cylinders. This cowling was also mounted in two other positions—in front and in the rear of the middle position. Cowling F weighs 21 pounds.

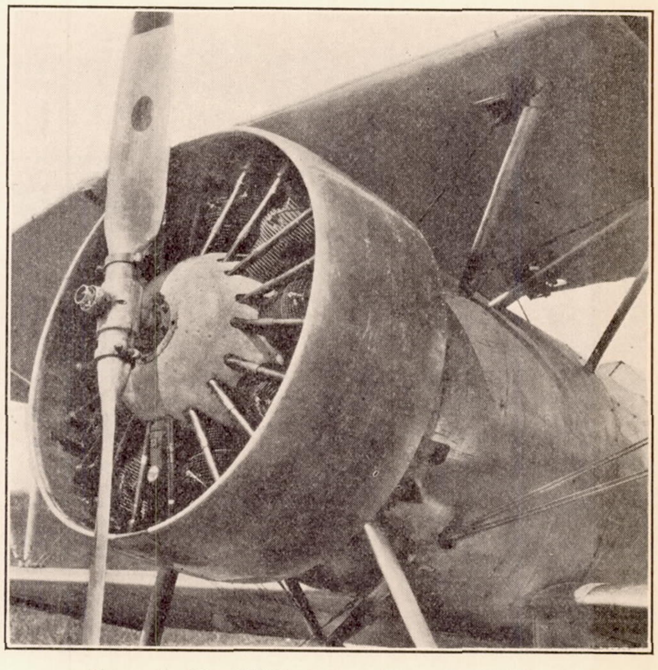


FIGURE 6.—The *XF7C-1* airplane with cowling 3-G-Front

Cowling G.—Cowling G (figs. 3 and 6) is a ring 21¼ inches wide, with its cross section resembling a thin low-cambered airfoil. The diameter at the nose is 1¼ inches smaller than at the rear and is one-half inch larger than the maximum engine diameter of $50\frac{5}{8}$

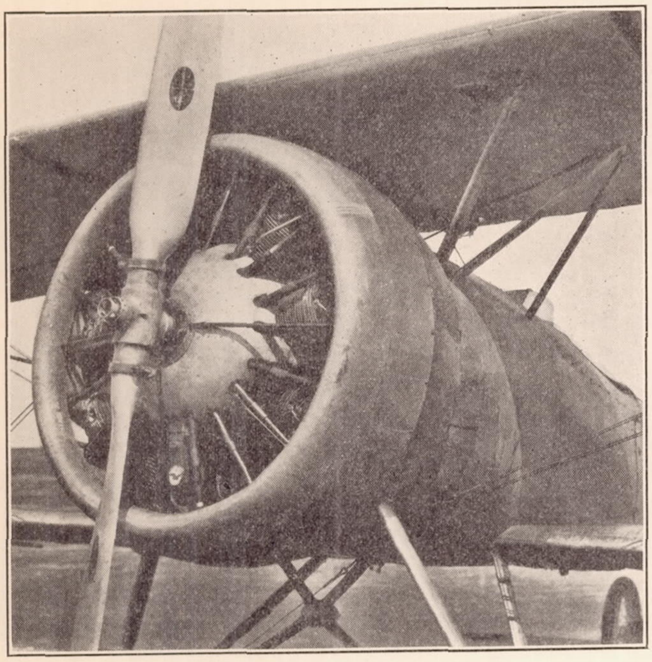


FIGURE 7.—The *XF7C-1* airplane with cowling 3–J

inches. Thus the chord of the cowling section is at a negative angle of approximately $1\frac{1}{2}°$ with respect to the thrust line. In its front position (fig. 6) the leading edge of cowling G was $9\frac{1}{4}$ inches forward of the cen-

Cowling H.—Cowling H was made by extending the skirt of cowling G six inches. (Fig. 3.)

Cowling J.—Cowling J (figs. 3 and 7) is a wide ring cowling with a section thick enough so that part of the cowling can be used as an exhaust-collector ring. The rear portion of the cowling, which is used for collecting the exhaust gases, is made of $\frac{3}{64}$-inch sheet iron, and the front portion is of sheet aluminum. The exhaust gases are discharged through a $\frac{1}{2}$-inch slot in the trailing edge along the lower half of the cowling. This cowling weighs $106\frac{1}{2}$ pounds, but since it replaced the service exhaust stacks, which weighed 19 pounds, the net weight added was $87\frac{1}{2}$ pounds.

Cowling JM.—Cowling JM (figs. 3 and 8) has the same shape as the outer line of cowling J, but is 1 inch smaller in diameter. It has only the single surface. The leading edge is formed around a $\frac{3}{4}$-inch steel tube. The weight of cowling JM is 45 pounds.

Cowling VA.—The variable-angle cowling (cowling VA) is shown in Figures 3 and 9. This is a ring type that was designed to determine the effect of changing the angle of the cowling section with respect to the thrust line. It is constructed of nine straight sections, one over each cylinder head, each of $17\frac{1}{4}$-inch chord and 13-inch span and pivoted near the front on a steel-tube mounting ring. Filler pieces make a fairing between the straight sections regardless of the angle at which they may be set. The angle of the chord of the straight sections with the thrust line could originally

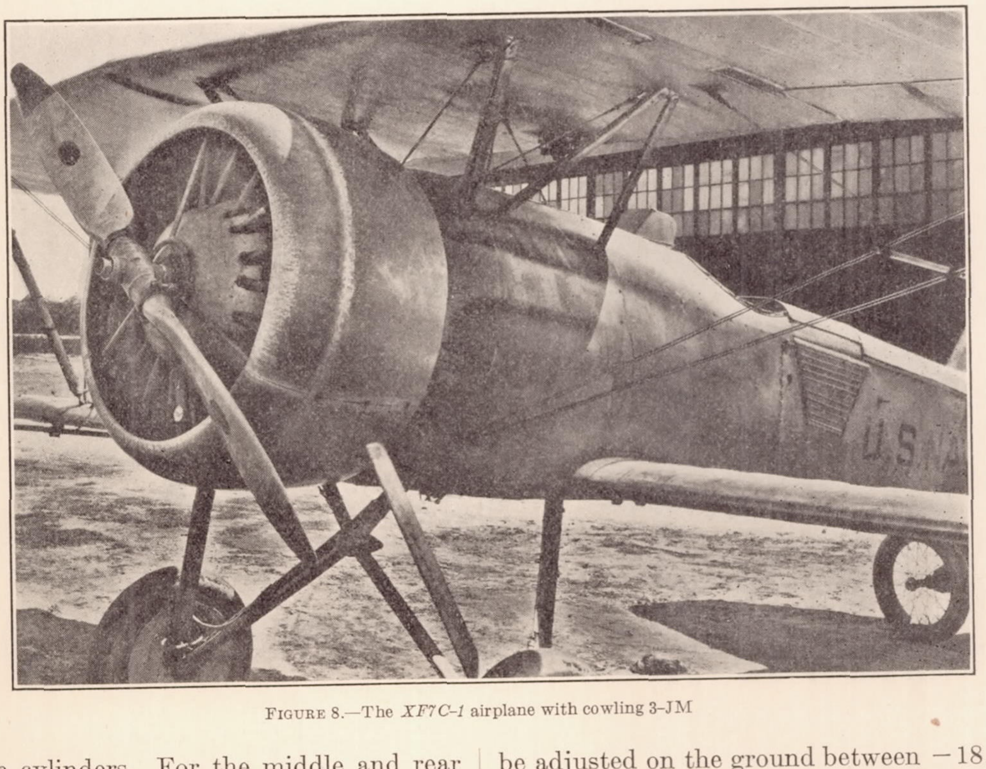


FIGURE 8.—The *XF7C-1* airplane with cowling 3–JM

tral plane of the cylinders. For the middle and rear positions this distance was reduced to $6\frac{1}{2}$ and $3\frac{3}{4}$ inches, respectively. The weight of cowling G with its supporting brackets is 40 pounds.

be adjusted on the ground between $-18.8°$ and $-4.7°$. This range did not cover the optimum position with fuselage 1, however, so for this fuselage the mounting ring was made $2\frac{5}{16}$ inches larger in diameter. With the

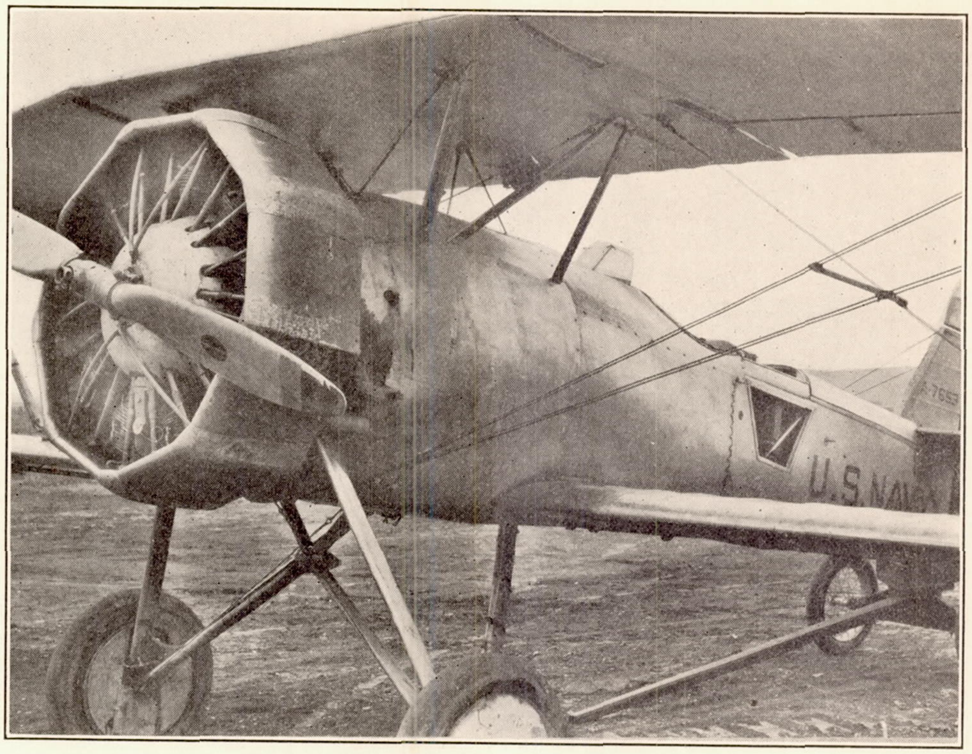


FIGURE 9.—The *XF7C-1* airplane with cowling 3-VA

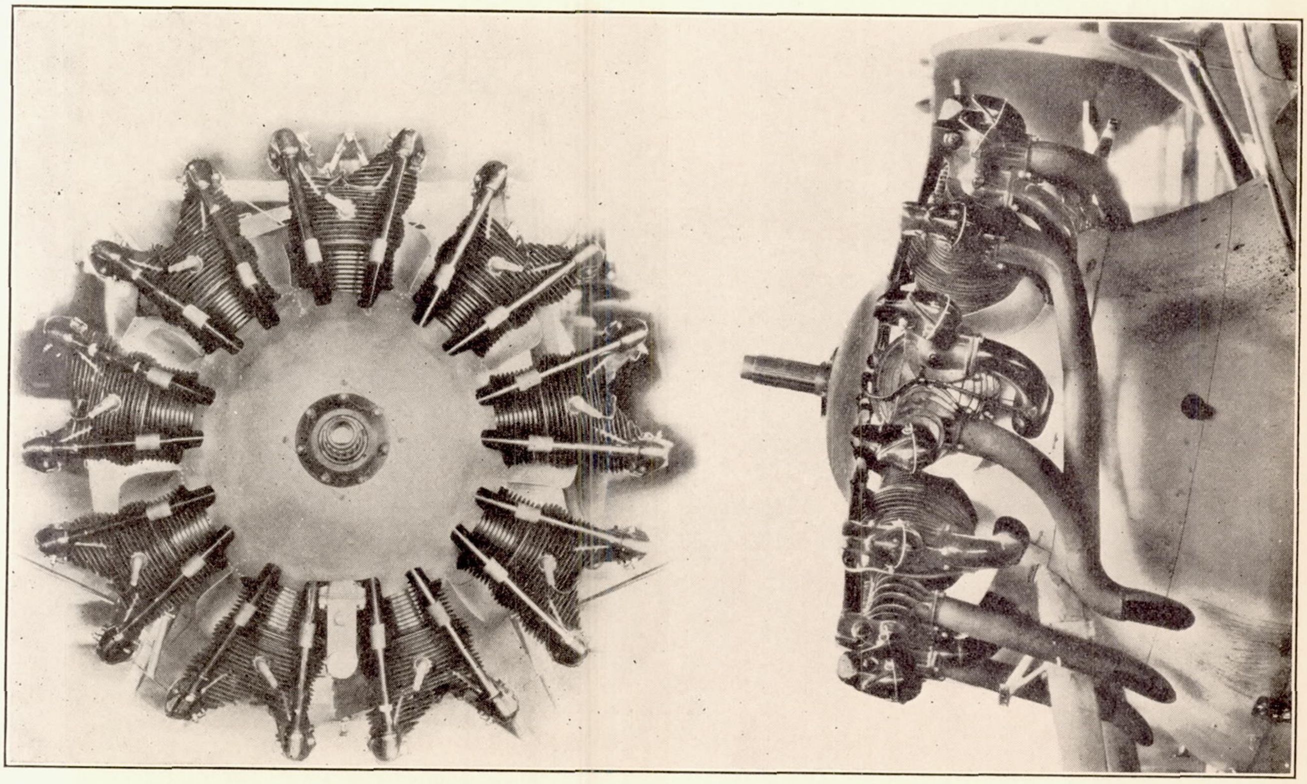


FIGURE 10.—The *XF7C-1* airplane with fuselage 2 without outer cowling, showing shape and location of deflectors

new cowling the angle could be varied from −18.8° to +6.4°. This cowling was not expected to be the equal of a smooth circular ring, but its design was made as clean as possible considering the necessity of changing its angle with the thrust line. Cowling VA weighs 36 pounds, complete with mounting brackets.

Symbols.—The fuselage numbers and cowling letters are combined to show any cowling conditions; thus, 2–F–Middle means fuselage 2 with cowling F in the middle position.

Deflectors were used behind each cylinder with fuselages 2 and 3 to improve the cooling. The construction of fuselage 1 did not lend itself to the addition of deflectors. The construction of the sheet-aluminum deflectors can be clearly seen in Figure 10.

The flight-test instruments were installed just behind the pilot's seat. They consisted of two electrical-resistance thermometers to measure the temperatures of the thermocouple cold junctions and of the atmosphere, a recording altimeter and air-speed meter, two pyrometers, a tachometer, and an indicating air-speed meter. All instruments except the recording altimeter and air-speed meter were mounted in an automatic observer. This is a light-tight box with a motor-driven motion-picture camera at one end focused on the dials of the instruments, which are mounted in the opposite end and illuminated by an electric lamp which flashes for each picture. Eighteen iron-constantan thermocouples were fixed to the engine cylinder barrels and heads, and were connected successively to the pyrometers by means of an automatic switch driven from the camera motor.

The high speed in level flight of the airplane was obtained for each cowling condition, except for one or two which caused overheating and were not flown. While the airplane was flown at an altitude of about 30 feet over a measured course, the time was taken with a stop watch by the pilot. Flights were made in both directions, and the average speed was taken as the true speed. Speed flights were not made when the wind was across the course. The timed speed was measured with a probable precision of ±0.5 m. p. h. A check of the speed with cowling 1–A for 8 tests covering a period of 10 months showed a variation of only ±1.8 m. p. h.

Full-throttle climbs were made with enough different cowling conditions to show the effect of the cowlings upon climb. At the start of the tests a series of climbs was made at different air speeds. Thereafter each climb was made at the air speed which had been found to be best. Each climb lasted 10 minutes, a time sufficiently long to furnish reliable climb data and to assure a constant engine temperature. The airplane performance in climb was computed according to the Lesley method given in reference 8.

Full-throttle level-flight runs for 15 minutes at approximately 1,500 feet altitude were made with each cowling condition that was tested in climb. The most unfavorable conditions for engine cooling were considered to occur during either the climbs or the high-speed level flights.

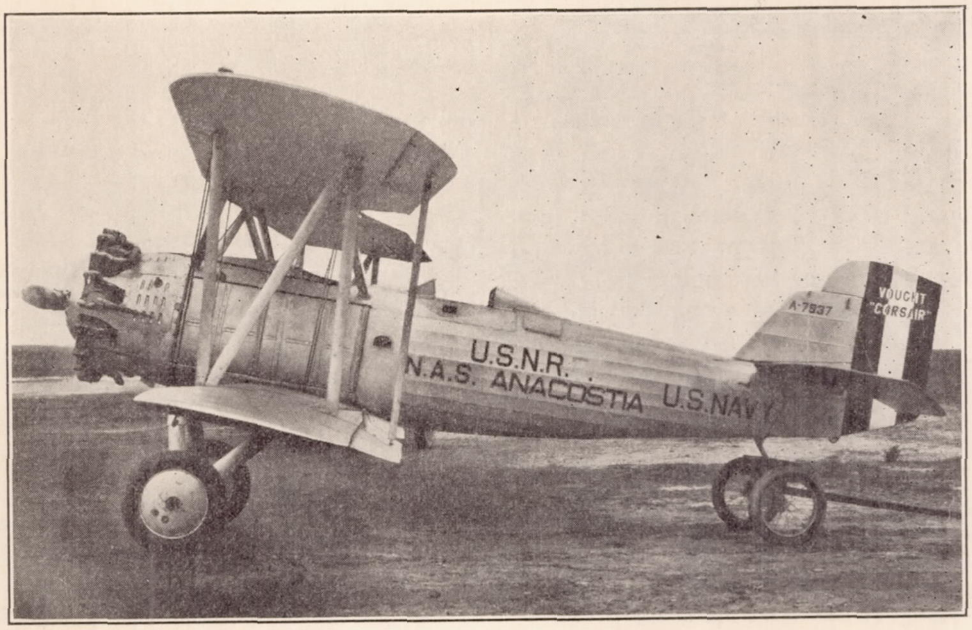


FIGURE 11.—The *O2U-1* airplane with service fuselage and no outer cowling

"O2U-1" AIRPLANE

The Vought *O2U–1* is a 2-place observation plane (fig. 11) powered with a Pratt & Whitney Wasp engine rated at 450 hp. at 2,100 r. p. m. The weight of the airplane with service cowling, pilot, observer,

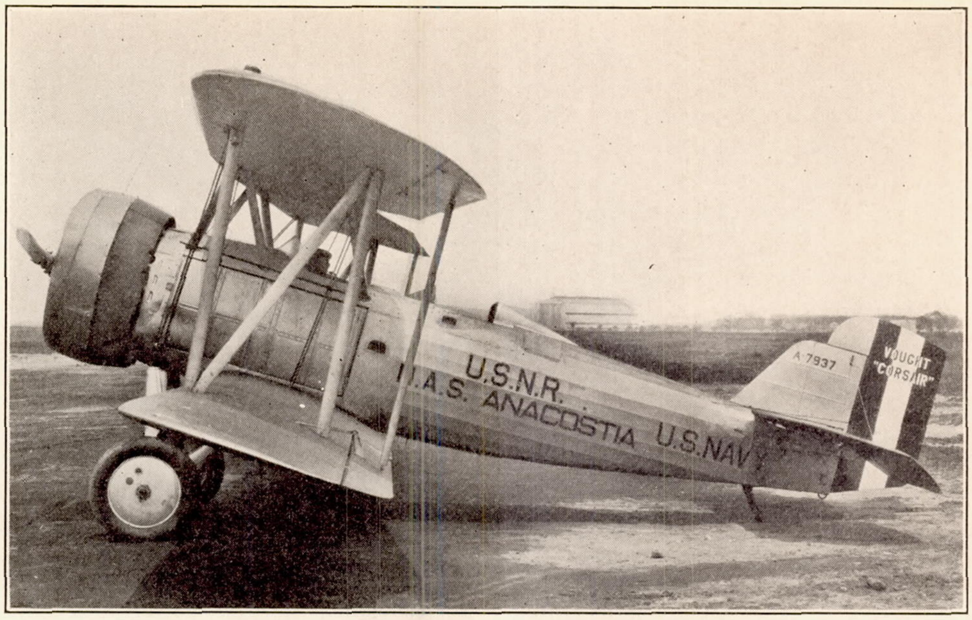


FIGURE 12.—The *O2U–1* airplane with service fuselage and cowling J

and parachutes was 3,045 pounds at the take-off. It was very lightly loaded, for with a full service load this airplane weighs 3,720 pounds. The service cowling for this airplane is of conventional design and includes hand-operated nose shutters together with a series of louvers at the rear of the engine.

Two aluminum-alloy adjustable-blade propellers (Navy drawing No. 3792) were used in the tests of the *O2U–1*, one of which had been cut from 10-foot

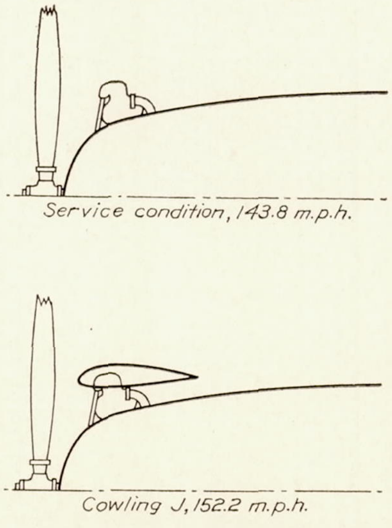


FIGURE 13.—The nose of the *O2U–1* airplane in the service condition and equipped with cowling J

to 9-foot diameter. The 9-foot propeller was the one used in the tests with the *XF7C–1*. Both propellers were used for similar tests, with pitch-angle settings that would allow propeller speeds of approximately 2,100 r. p. m. in full-throttle flight at sea level.

The high speed of this airplane was determined over the measured course with the service cowling and with cowling J over the service cowling. (Figs. 11, 12, and 13.) No change was made in the service cowling when mounting the exhaust-collector ring. It was possible to secure the outer cowling with brackets attached to the exhaust-port studs in the same way that it was attached to the engine of the *XF7C–1*.

"FC2W–2" AIRPLANE

The Fairchild *FC2W–2* is a 5-place high-wing cabin monoplane. (Fig. 14.) It is powered with a Pratt & Whitney Wasp engine developing 400 hp. at 1,900

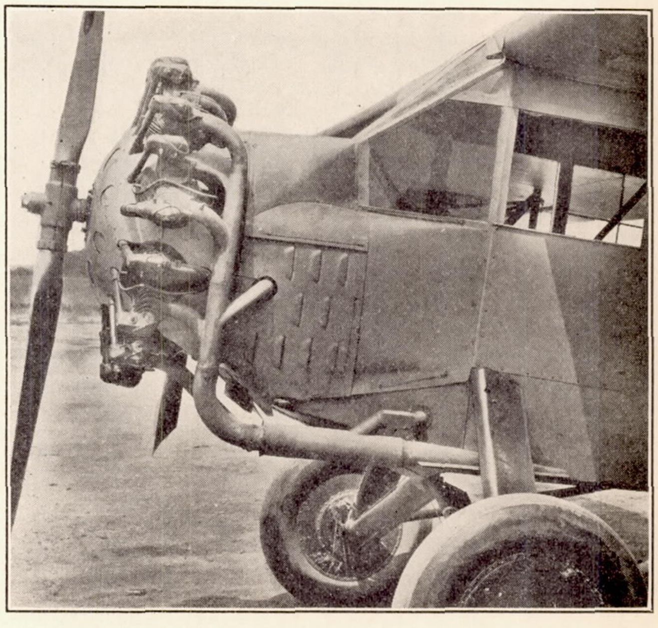


FIGURE 14.—The *FC2W–2* airplane with service fuselage and no outer cowling

r. p. m. This airplane with its service cowling and with the pilot, but with no passengers, weighed 3,573 pounds at take-off. The standard cowling for this airplane is of conventional design, having hand-operated nose shutters and louvers behind the engine. The streamlining of the engine cowling with the fuselage proper is poor, particularly when used in combination with a ring cowling for reducing drag.

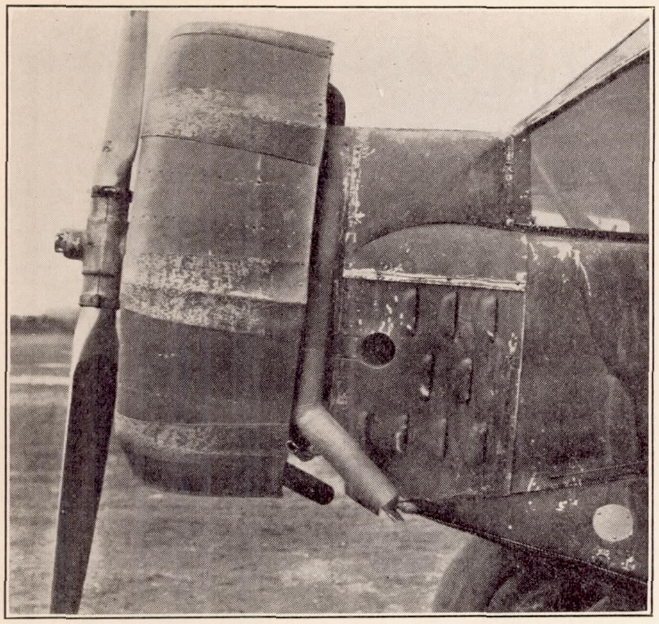


FIGURE 15.—The *FC2W-2* airplane with service fuselage and cowling VA

The high speed with the service cowling and with cowlings C, F, G, and VA (fig. 15 and 16) over the service cowling was determined by making full-throttle runs over the measured course. No change in the service cowling was required for the proper mounting of the outer cowlings used. In these tests the original exhaust manifolds were replaced by the exhaust stacks used on the *XF7C-1*.

TABLE I

HIGH SPEED IN LEVEL FLIGHT OF THE XF7C-1 AIRPLANE FOR ALL COWLING CONDITIONS EXCEPT THOSE WITH COWLING VA

Cowling	Timed speed, m. p. h.	Engine speed, r. p. m.	Propeller pitch setting at 42-in. radius, degrees
3-JM	168.1	1,975	20.5
1-JM	165.7	1,995	20.5
3-E	165.3	1,960	20.5
3-G-Rear	164.3	1,950	20.5
3-C	164.0	1,950	20.5
3-D	163.6	1,945	20.5
2-D	162.2	2,000	20.0
1-J	161.6	2,000	20.0
3-H-Front	161.4	1,945	20.5
3-G-Front	161.2	1,945	20.5
2-J	159.5	1,970	20.5
3-J	159.0	1,935	20.5
2-G-Rear	159.0	1,950	20.5
2-G-Middle	158.0	1,950	20.5
1-G-Rear	157.3	1,960	20.0
1-G-Middle	157.0	1,960	20.0
2-G-Front	157.0	1,950	20.5
1-G-Front	156.3	1,945	20.0
3-F-Middle	156.1	1,910	20.5
2-F-Rear	154.2	1,940	20.5
2-F-Front	153.5	1,935	20.5
2-H-Front	153.5	1,885	20.5
2-F-Middle	152.3	1,925	20.5
1-F-Middle	151.2	1,945	19.5
3-A	149.0	1,880	20.5
2-A	146.3	1,890	20.5
1-A	145.2	1,940	19.5

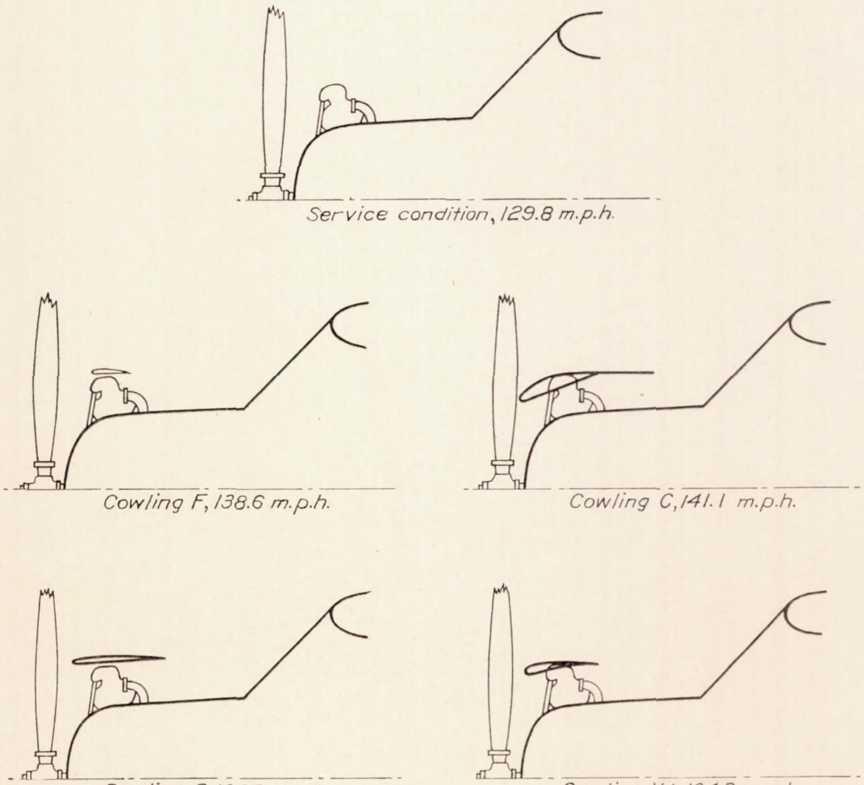
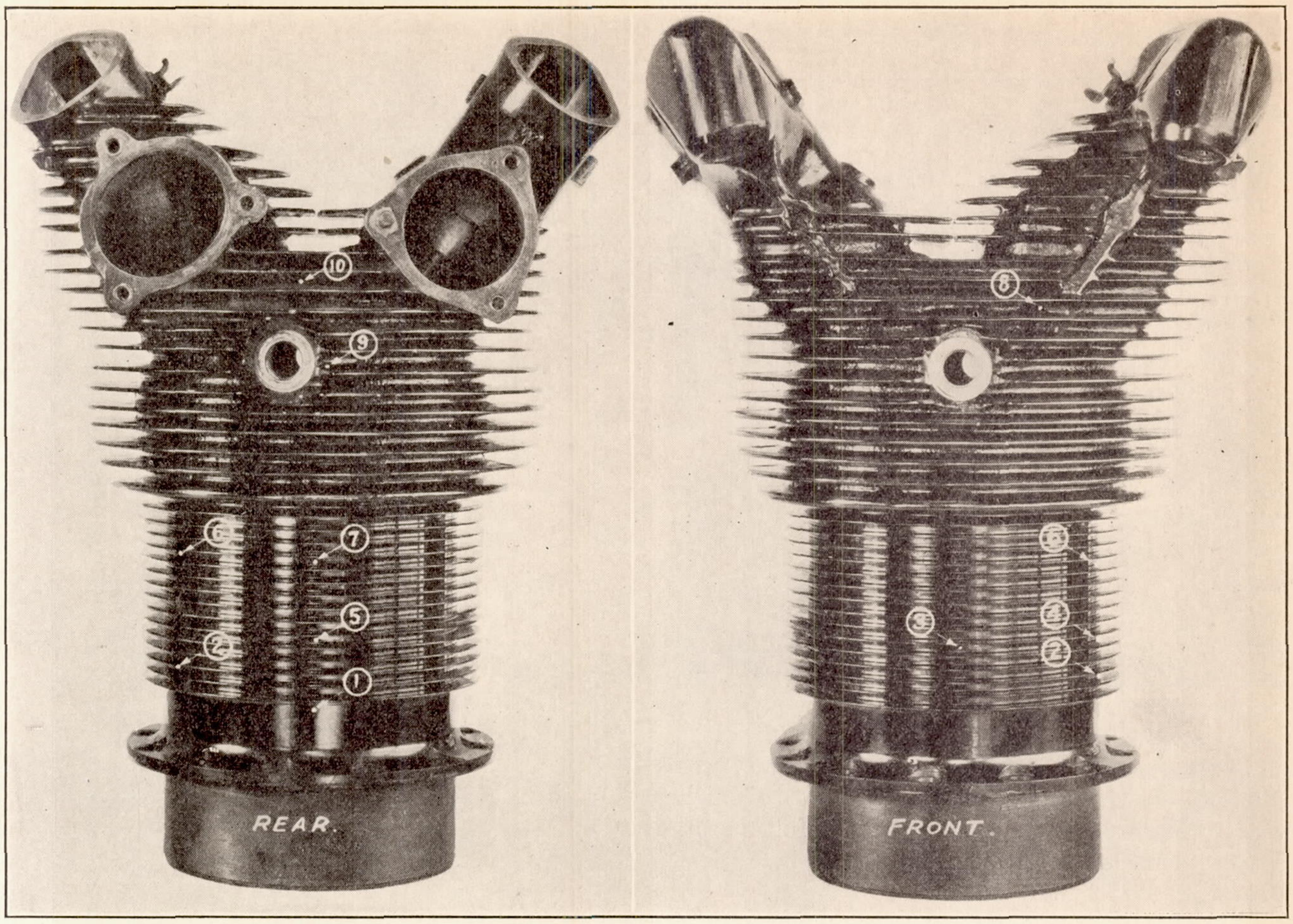


FIGURE 16.—The nose of the *FC2W-2* airplane with service fuselage and four types of outer cowling



NOTE.—The thermocouple locations shown are for cylinder No. 1. Thermocouples Nos. 11 to 18 for cylinders Nos. 2 to 9, respectively, were located at the same point as thermocouple No. 10 on cylinder No. 1

TABLE II

CYLINDER TEMPERATURES (DEGREES F.) OBTAINED WITH THE XF7C–1 AIRPLANE IN CLIMB AND LEVEL FLIGHT AT THE VARIOUS POINTS NOTED ON THE PHOTOGRAPH

Cowling	Climb or level flight	Atmospheric temperature at ground at start of flight	Cylinder No. 1										Cylinder No. 2	Cylinder No. 3	Cylinder No. 4	Cylinder No. 5	Cylinder No. 6	Cylinder No. 7	Cylinder No. 8	Cylinder No. 9
			Thermocouple No.																	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
3–J M	Climb	64	------	320	------	340	------	390	------	------	------	------	445	------	475	------	420	465	460	400
	Level	62	------	255	------	265	------	365	------	------	------	------	515	------	605	------	550	585	550	470
1–J M	Climb	76	360	300	280	305	380	365	405	380	440	440	510	480	525	490	475	------	490	405
	Level	76	370	295	235	275	365	390	420	400	495	500	520	470	585	515	545	------	510	485
2–D	Climb	72	310	225	255	185	320	265	340	410	390	405	415	490	460	500	465	480	450	265
	Level	70	335	230	240	220	315	320	370	410	465	440	455	535	550	540	560	550	515	445
1–J	Climb	66	------	250	------	220	------	305	------	------	------	------	380	------	435	------	460	450	460	390
	Level	46	320	210	185	200	340	295	405	425	470	405	350	470	410	515	455	440	450	395
2–J	Climb	71	345	230	305	200	330	295	380	415	440	440	400	470	450	485	455	470	490	440
	Level	82	355	230	270	215	325	295	380	445	455	455	435	485	440	470	485	485	490	485
3–J	Climb	76	------	285	------	275	------	345	------	------	------	------	415	------	470	------	440	480	480	460
	Level	76	------	305	------	285	------	360	------	------	------	------	480	------	495	------	475	505	505	515
2–G–Rear	Level	39	325	215	215	205	300	295	375	410	475	440	440	495	470	490	490	475	475	455
2–G–Middle	Level	34	305	210	205	185	265	280	345	435	485	410	425	465	450	465	475	470	460	455
2–G–Front	Climb	40	320	210	250	210	305	255	335	365	390	355	375	470	405	470	410	405	415	325
	Level	37	280	170	205	155	270	225	330	375	410	345	400	495	440	475	460	460	475	380
1–G–Front	Climb	54	295	260	190	240	295	285	360	375	400	355	350	400	400	440	400	370	395	355
	Level	36	300	210	170	175	280	270	345	410	410	365	340	410	400	450	415	370	370	345
2–F–Front	Climb	39	315	220	255	185	305	265	340	390	405	375	370	425	385	430	395	400	410	375
	Level	42	295	185	205	185	250	260	330	420	450	390	390	440	410	440	430	435	435	430
1–F–Middle	Climb	65	------	260	------	245	------	335	------	------	------	------	400	------	430	------	420	400	415	395
	Level	54	------	270	------	245	------	355	------	------	------	------	410	------	475	------	465	465	450	435
2–A	Climb	46	300	170	220	150	275	190	335	355	395	370	325	425	345	420	355	385	385	310
	Level	48	290	170	190	145	260	210	305	350	400	395	345	420	380	430	395	410	395	350
1–A	Climb	76	------	255	------	245	------	315	------	------	------	------	360	------	365	------	365	365	380	370
	Level	68	------	200	------	180	------	270	------	------	------	------	375	------	365	------	370	355	375	360

RESULTS AND DISCUSSION OF RESULTS

To facilitate a general comparison of the high-speed performance for the many fuselage and cowling combinations used with the *XF7C–1* airplane, the high speeds are given in Table I in the order of their magnitude, and in Figure 3 they are given with most of the sketches of the cowlings tested. The engine speed and the propeller pitch setting are also given in Table I for each cowling condition. The cylinder temperatures for many of the fuselage and cowling combinations are given in Table II.

Effect of fuselage shape.—The maximum air speeds obtained without outer cowlings were 145.2, 146.3, and 149 miles per hour with fuselages 1, 2, and 3, respectively. The engine speed and propeller pitch setting for each condition are given in Table I. Appreciably higher speeds were obtained with the modified fuselage than with the service fuselage, and this difference would have been slightly greater if the propeller pitch had been changed so that the engine speeds with fuselages 2 and 3 had been the same as with fuselage 1.

The engine temperatures given in Table II for cowlings 1–A and 2–A show that the cooling was satisfactory with either fuselage when no outer cowling was used. No temperatures were measured with cowling 3–A, but since the shape at the engine is the same as that of cowling 2–A (fig. 2) it is assumed that the temperatures would not be greatly different. In general, the cylinder temperatures with cowling 2–A are somewhat lower than with cowling 1–A. The difference would be more marked if the atmospheric temperatures had been more nearly the same for flights with the two cowlings. The temperatures at the base of the cylinder with cowling 1–A are much higher in climb than in level flight, while those for cowling 2–A show very little change. In no case are the cylinder temperatures excessive. With cowling 2–A the lower part of the cylinder would undoubtedly run too cold for some flight conditions. When an outer cowling is used with this fuselage, as was originally intended, the temperatures near the base of the cylinder are raised somewhat.

Effect of width of ring cowling.—The difference between the maximum air speeds obtained with the narrow-ring and with the wide-ring cowling on the same fuselage (Table I) was consistently in favor of the wide ring, and amounted to from 5 to 8 miles per hour. The wide ring in the best (rear) position increased the speed, over that obtained with no outer cowling, 12.1 miles per hour with fuselage 1 and 15.3 miles per hour with fuselage 3, whereas the narrow ring did not give an increase of more than 8 miles per hour for any condition. The difference in speed between these two fuselages without any outer cowling was 3.8 miles per hour, as seen from Table I. With a wide-ring cowling the maximum difference was 7 miles per hour in favor of fuselage 3.

The use of cowling H, which is 6 inches wider than cowling G, resulted in only a negligible improvement in high-speed performance. Although no tests were made to determine how much the width of cowling G could be decreased without appreciably reducing the high-speed performance, it is believed that to reduce the width to less than 18 inches would result in a reduction of high speed of 2 to 3 miles per hour. In recent speed-course tests of a Boeing *XF5B–1* and a Boeing *P–12*, both with and without a 16-inch ring cowling with which both of these airplanes are regularly equipped, the cowling increased the speed of the *XF5B–1* 8.7 miles per hour, from 163.4 to 172.1 miles per hour, and of the *P–12* 9.1 miles per hour, from 155.3 to 164.4 miles per hour.

No cooling difficulties were experienced with cowlings F or G when used with any of the three fuselages. The temperatures of the lower part of the cylinder in climb or level flight when the cowling is used in the front position are the same for the wide-ring as for the narrow-ring cowling, whereas the head temperatures for the same condition are slightly higher with the wide-ring cowling. Increasing the width of cowling G to form cowling H restricted the flow passages on fuselage 2 so that the air flow was insufficient to cool the engine properly when operating at full throttle.

Effect of position of outer cowling.—The effect on the high-speed performance of the location of the outer cowling with respect to the center line of the cylinders was investigated, using cowling G in the front, middle, and rear positions (fig. 3) on each of three fuselages and cowling F for several cowling combinations. The results given in Table I show that the highest speeds are obtained with the wide ring in the rear position and the lowest with it in the front position; the differences, however, are small, amounting to 1, 2, and 3.1 miles per hour for fuselages 1, 2, and 3, respectively. Three positions of cowling F were tried only on fuselage 2. The rear position gave the highest speed, as with cowling G, but the front position was slightly superior to the middle position.

The effect on the cylinder temperatures of locating the wide ring in the front, middle, and rear positions was determined for fuselage 2. The results indicate that the engine temperatures are lower with the cowling in the front position than in either the middle or rear position; the difference in level flight averages about 40° F. for the barrel of cylinder No. 1 and 30° F. for all the rear spark-plug bosses. The cylinder temperatures are highest for the cowling position which gives the best high-speed performance. The cooling is best with the cowling in the front position, probably because more of the diverging air flow just in front of the engine is directed past the cylinder heads than with the cowling in the rear position.

In level flight the temperatures at the base of the cylinder for cowling 2–G–Front are practically the same as for cowling 2–A, although the cylinder-head temperatures are higher. In condition 2–G–Rear all cylinder temperatures are higher than for 2–A, by an average amount of 40° F. on the lower part of the cylinders and 60° F. on the heads. In climb with cowling 2–G–Front the barrel temperatures average about 35° F. higher than in level flight, while the rear spark-plug-boss temperatures in climb for the nine cylinders average about 35° F. lower than in level flight.

Effect of the angle between the outer cowling and the thrust line.—The effect on the high-speed performance of varying the angle of the outer cowling sections with the thrust line is shown for the three different fuselages by the curves in Figure 17. Note that the best angle and the range of the angle giving nearly the maximum performance depend upon the shape of the nose of the fuselage. The proper angle for the outer cowling probably depends upon the size of the fuselage along which the air is to be directed, assuming a given engine and cowling diameter. The setting of the cowling angle could be expected to be more critical for fuselages 2 and 3 than for fuselage 1, because of the sharp curves in these fuselages just behind the engine. The curves in Figure 17 indicate that an angle from −4° to −8° for a ring of this cross section would probably be satisfactory for any conventionally shaped fuselage. With fuselage 3 the maximum speed is obtained when the section of the cowling is at an angle of −8°, and with the same fuselage the maximum speed is reduced to that with no outer cowling when the cowling angle is increased to −16°. This result indicates the importance of having the angle correct within 1° or 2°.

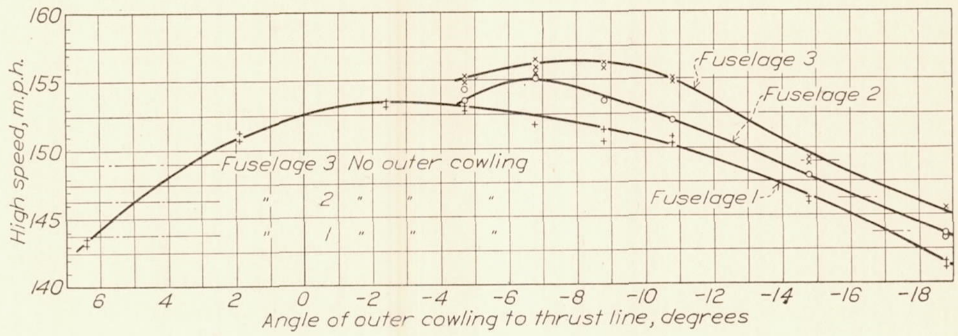


FIGURE 17.—Variation of high speed of *XF7C-1* airplane with angle of outer cowling

TABLE III

CYLINDER TEMPERATURES (DEGREES F.) AS OBTAINED IN CLIMB AND LEVEL FLIGHT WITH THE VARIABLE-ANGLE COWLING ON THE XF7C-1 AIRPLANE

	Cowling position	Climb or level flight	Atmospheric temperature at ground at start of flight	Cylinder No. 1										Cylinder No. 2	Cylinder No. 3	Cylinder No. 4	Cylinder No. 5	Cylinder No. 6	Cylinder No. 7	Cylinder No. 8	Cylinder No. 9
				Thermocouple No. (For location see Table II)																	
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Fuselage 3	−4.7°	Climb	62	-----	250	-----	235	-----	235	-----	-----	-----	-----	365	-----	435	-----	450	440	480	425
		Level	62	-----	250	-----	220	-----	220	-----	-----	-----	-----	425	-----	455	-----	480	465	470	430
	−10.8°	Climb	61	280	260	170	235	288	235	280	325	345	345	360	370	415	430	445	440	460	415
		Level	61	255	225	165	200	255	200	300	360	450	425	415	405	435	445	455	455	460	440
	−18.8°	Climb	94	310	285	200	270	310	270	330	350	395	415	415	440	455	440	460	465	470	430
		Level	94	310	270	225	245	310	245	335	395	440	460	415	440	445	460	440	450	450	435
Fuselage 2	−4.7°	Climb	48	340	255	265	213	325	235	290	405	435	420	360	440	360	360	315	365	450	445
		Level	48	340	230	210	205	300	205	300	420	445	420	430	470	395	430	375	445	475	490
	−8.8°	Climb	53	335	230	220	215	300	215	300	370	425	390	340	440	365	325	275	370	430	420
		Level	53	325	215	180	200	275	200	315	375	415	375	365	435	340	345	365	420	425	425
	−18.8°	Climb	54	340	220	215	220	285	220	380	350	395	370	525	420	565	570	305	385	415	405
		Level	54	300	210	180	200	260	200	290	365	415	385	405	450	340	325	330	415	425	440
	No outer cowling	Climb	46	300	170	220	150	275	150	335	355	395	370	325	425	345	420	355	385	385	310
		Level	46	290	170	190	145	260	145	305	350	400	395	345	420	380	430	395	410	395	350

Considering that the 9-inch ring (cowling F) gave an increase in speed of 7 to 8 miles per hour and that the 21-inch ring (cowling G) gave an increase of as much as 15 miles per hour, one would naturally expect that cowling VA of 17-inch width would give more than 9 miles per hour increase when set at the best angle. Apparently the polygonal shape is much less efficient than a circular shape.

The temperatures obtained in climb and level flight with cowlings 2–VA and 3–VA are given in Table III. In level flight with fuselage 2 the cylinder temperatures increased slightly as the angle of attack of the cowling section was increased from $-18.8°$ to $-4.7°$. With fuselage 3 there was no appreciable change in cylinder temperatures with change in cowling angle. The high temperatures observed on cylinders 2, 4, and 5 in climb with cowling 2–VA–($-18.8°$) are probably due either to detonation or an error in the instruments.

Effect of shape of cowling.—Data have already been presented showing that a polygonal cowling of sufficient width and when set at the best angle, is not equal to a circular-ring cowling and that a narrow-ring cowling is not equal to a wide-ring cowling for increasing the speed of an airplane. Other shapes of outer cowling are represented in these tests by three variations of the nose piece of the original N. A. C. A. cowling, by the exhaust-collector ring, and by the single-wall cowling shaped like the outer surface of the exhaust-collector ring, cowlings C, D, E, J, and JM, respectively.

The high-speed performance obtained with cowlings C, D, E, J, and JM is given in Table I and the cylinder-temperature measurements for most of the conditions several cowling shapes. It seems probable that cowling 1–J does not cause overheating because the cooling air is flowing at its highest velocity in the plane of the engine cylinders. With cowling 2–J, on the other hand, although the minimum area is no smaller, the area at the engine is larger, and the cooling air is not so effective at the reduced velocity.

Poor cooling may readily accompany the use of a cowling which gives the maximum increase in high-speed performance. Limiting the amount of cooling air reduces the drag, and so improves the speed, but at the same time increases the danger of overheating the engine. It follows that for maximum performance the cooling air admitted should be carefully directed and be so limited in amount as to just properly cool the engine.

Effect of engine cowlings in climb.—The many cowling and fuselage combinations tried had very little effect on the rate of climb, but the cylinder temperatures in climb, as in level flight, were greatly influenced by the type of cowling used. The test results presented

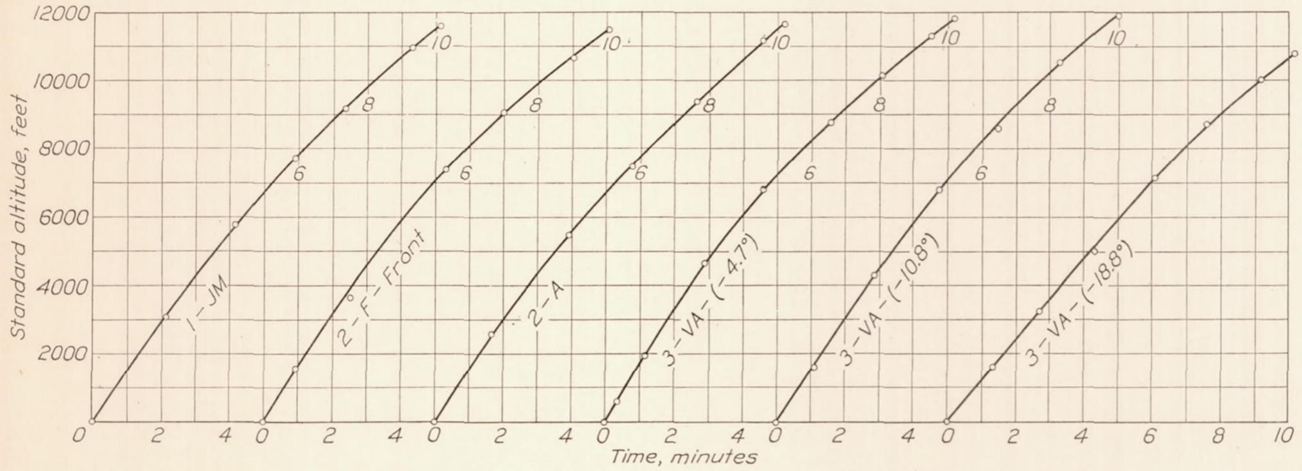


FIGURE 18.—Time-altitude curves for full-throttle climbs with several of the cowlings tested on the *XF7C-1* airplanes

are given in Table II. It may be noted that the use of any one of these cowlings gave a large improvement in high speed for practically every fuselage condition; the improvement was superior to that obtained with any other type of outer cowling except cowling G in the rear position for fuselage 2. The cylinder temperatures obtained with these outer cowlings were in some cases excessive and in all cases, except 2–G–Rear, were higher than those obtained with the cowlings of thin airfoil cross section.

A study of the engine temperatures as influenced by the shape of the outer cowling enables one to draw some interesting conclusions. It appears reasonable that the quantity of cooling air flowing between an outer cowling and the fuselage nose is regulated by the minimum cross-sectional area of the space between the two. Then the velocity at any other section varies approximately inversely as its area. This reasoning is borne out by the cylinder temperatures observed with in reference 5 show that although the use of a low-drag cowling resulted in but a slight improvement in the rate of climb for most cowling conditions it did not, however, impair the climb for any cowling condition. This was, in substance, later verified in tests with the variable-angle cowling. (Reference 6.) In the tests with the variable-angle cowling it was found that with the cowling section at an angle with the thrust axis giving improved high-speed performance the climbing capabilities of the airplane were slightly improved although when the cowling was set at some angle that impaired the high-speed performance the climb performance was also poorer. The climb curves for a few of the cowling conditions tried are presented in Figure 18.

An analysis of the effect of a ring cowling on the climb of an airplane was recently made by J. A. Louden, of the Bureau of Aeronautics, Navy Department. (Reference 10.) The results of this analysis showed that when the high-speed performance was increased 8 per cent (165 to 178 miles per hour) the rate of climb was increased only 2 per cent.

The temperature measurements obtained in climb are presented in Tables II and III. An examination and comparison of these temperatures show that it is not unusual to obtain higher temperatures in level flight than in climb when an outer cowling is used. With the cowlings tested in this investigation the higher temperatures are most apt to occur when the annular opening between the rear of the outer cowling and the fuselage is restricted, as with cowlings D, J, and JM with fuselages 2 and 3.

With cowling VA the temperatures in climb were high when the cowling section was set at an angle of $-18.8°$, but with the cowling set at the best angle for high speed the temperatures in climb were satisfactory. In this investigation all cowling conditions which permitted satisfactory cooling in level flight were also satisfactory in climb.

Effect of fuselage and cowling shape on the field of vision.—The degree to which the pilot's field vision is impaired may be an important factor to be considered in the selection of a cowling. A general idea of how the vision with the different fuselages compares and of the extent to which the field of vision from each is impaired by the addition of an outer cowling may be obtained from Figure 3. Fuselages 2 and 3 are of greater diameter than fuselage 1, and consequently do not afford quite so good vision. However, the vision with fuselages 2 and 3 can not be appreciably impaired by the addition of an outer cowling unless the outer cowling is of greater diameter than the fuselage. The vision with fuselage 1 is always equal to or better than that with fuselages 2 and 3 because it is possible to obtain an unobstructed field of vision between the cylinders with some of the cowlings when used on this fuselage. The pilot's actual field of vision is clearly shown by the photographs in Figures 19 and 20.

Effect of cowlings upon stability.—The *XF7C-1* airplane in its service condition is practically neutrally stable. When any outer cowlings are added the longitudinal stability is impaired, as might be expected when a circular airfoil is placed in front of the center of gravity. The effect is more pronounced with the wider cowlings, such as G, but in no case is the instability serious enough to make the airplane difficult to control. No attempt was made to counteract the effect of the cowlings by increasing the area of the fixed tail surfaces or changing the location of the center of gravity.

Miscellaneous tests.—To obtain information on other airplanes concerning the effect on performance of adding an outer cowling, a few tests were made on a Vought *O2U-1* and a Fairchild *FC2W-2*. No attempt was made to measure the cylinder temperatures in these tests. The performance of the engine for all conditions was satisfactory, however, and there were no indications of high cylinder temperatures. The results of the high-speed tests on these two airplanes are given in Tables IV and V.

TABLE IV

EFFECT OF COWLING J UPON HIGH-SPEED PERFORMANCE OF VOUGHT O2U-1 WITH TWO DIFFERENT PROPELLERS

	Service cowling		Cowling J	
Propeller diameter, feet	10	9	10	9
Propeller setting at the 42-inch radius, degrees	17.2	18.3	17.7	19.2
Maximum propeller speed, r. p. m.	2,070	2,130	2,060	2,095
Timed high speed, m. p. h.	143.8	146.4	152.2	154.9
Speed increase due to cowling, m. p. h.			8.4	8.5

TABLE V

EFFECT OF FOUR TYPES OF OUTER COWLING UPON PERFORMANCE OF FAIRCHILD FC2W-2

	Service cowling	Cowling C	Cowling F	Cowling G	Cowling VA at $-6.8°$ setting
Propeller setting at the 42-inch radius, degrees	18.7	18.7	18.7	18.7	18.7
Maximum propeller speed, r. p. m.	1,780	1,840	1,840	1,835	1,775
Timed high speed, m. p. h.	129.8	141.1	138.6	137.9	134.2
Speed increase due to cowling, m. p. h.		11.3	8.8	8.1	4.4

The results show that the use of cowling J over the service cowling increased the speed of the *O2U-1* about 8.5 miles per hour. The same increase was obtained with each of the two propellers tried; however, the small-diameter propeller gave a little higher speed. The increase in speed from using the cowling was small when compared with the increase of 16.4 miles per hour obtained when cowling J was added over the service fuselage of the Curtiss *XF7C-1*. An examination of these fuselage and outer-cowling combinations as shown in Figures 3 and 13 indicates that the opening between the cylinders and the outer cowling is practically twice as large on the *O2U-1* as on the *XF7C-1*. As a result more air passes through and the disturbance and losses are greater, although the engine is undoubtedly better cooled.

Cowlings C, F, G, and VA were tried on the *FC2W-2* as shown in Figure 16. The results of these tests (Table V) show that the adding of an outer cowling increased the high speed in all cases. Cowling VA gave the least improvement, while cowling C gave the most. The increase with cowling F on this airplane was equal to that obtained on the *XF7C-1*. Cowling G gave slightly less improvement than cowling F; however, cowling G was used in the front position, which was found to be the poorest in the tests with the *XF7C-1*. None of these cowlings, except possibly

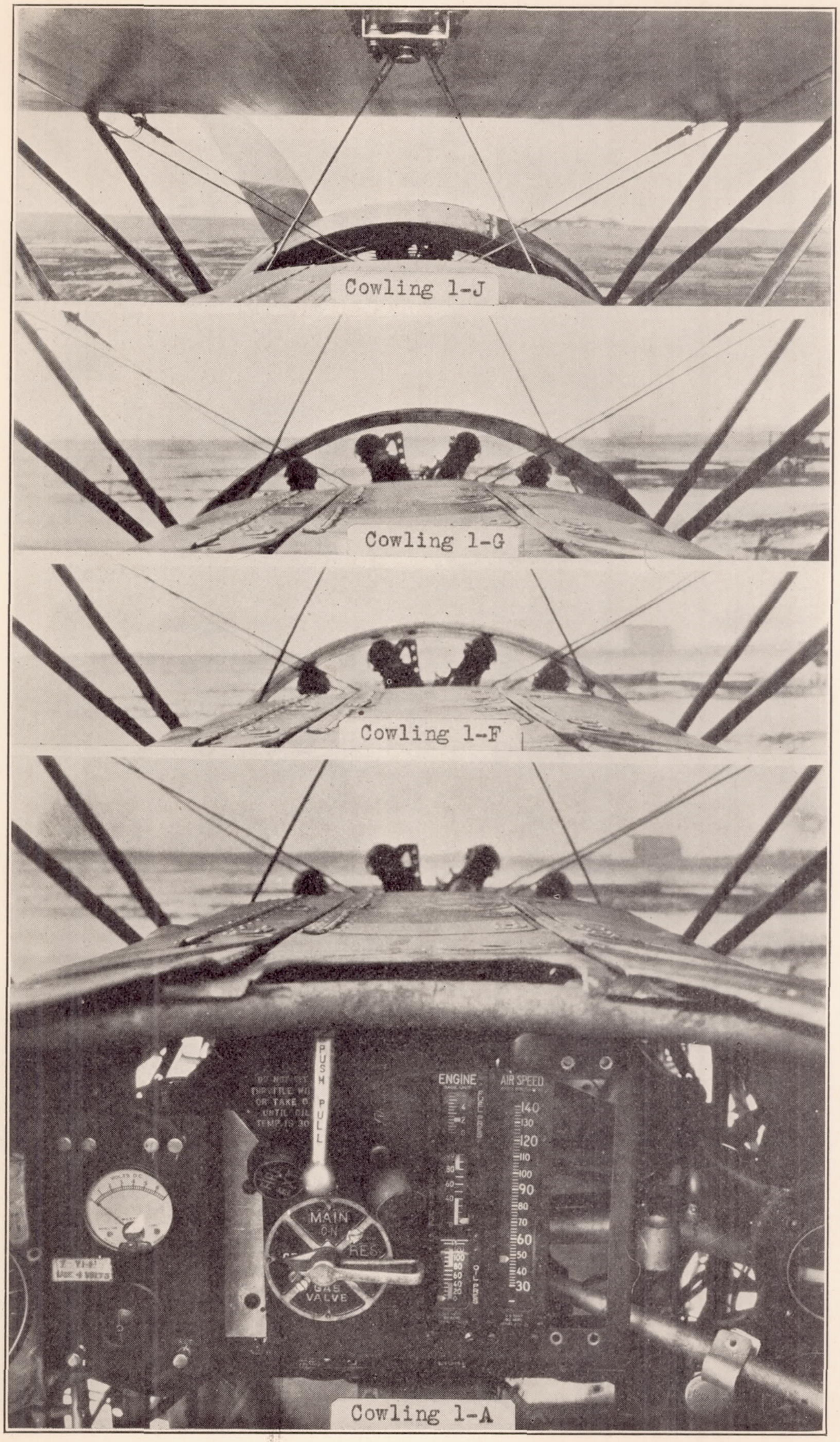


FIGURE 19.—Pilot's view forward with fuselage 1 as affected by the use of several different low-drag cowlings

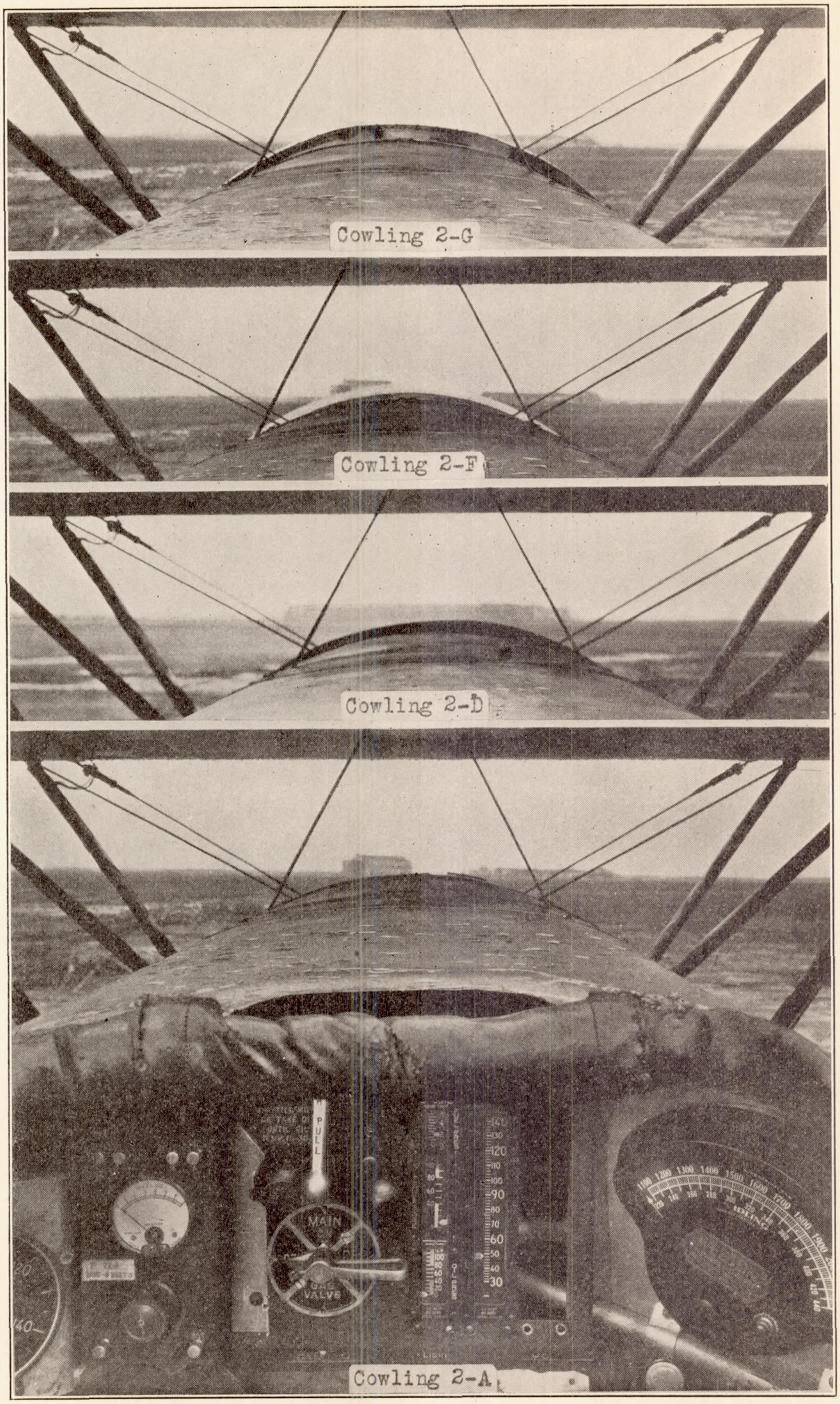


FIGURE 20.—Pilot's view forward with fuselage 2 as affected by the use of several different low-drag cowlings

cowling F, would be practicable on this airplane, for they obstructed the pilot's vision in an objectionable manner. They were tested only because it was desired to learn whether the various cowlings would affect the speed of different types of airplanes in a comparable manner. It is to be regretted that cowling JM could not have been tested with the *FC2W-2*. This cowling had not been constructed when these tests were made. On the basis of the tests on the *O2U-1* and the *FC2W-2* it seems probable that an improvement in speed can usually be obtained by adding an outer cowling over the service fuselage. However, better results may be expected if the cowling and fuselage are considered as a unit.

CONCLUSIONS

From the results of flight tests on the *XF7C-1* airplane with three fuselage nose shapes and six main types of outer engine cowling the following conclusions can be drawn:

1. The best performance is obtained by designing the fuselage and outer cowling to function together, although reasonably large improvements in speed can be obtained by adding an outer cowling over the conventional fuselage.

2. The increase in high-speed performance is sensitive to the width of the outer cowling up to a limit of about 21 inches for the type of ring tested; a cowling of 9-inch width gave an increase in speed of 9 miles per hour for the best condition, and a cowling of 21¼-inch width gave an increase of 16.4 miles per hour. Increasing the width to more than 21¼ inches resulted in only a negligible improvement in the high-speed performance. Increasing the width does not affect the cooling of the engine unless the flow passages are restricted.

3. Locating the relatively thin and flat type of ring cowling so that its leading edge is approximately flush with the front plane of the cylinders gives better high-speed performance than if the cowling is farther forward; the cooling, however, is better in the front position.

4. The angle at which the section of the variable-angle cowling was set with respect to the center line of the crankshaft was very important, as changes of only a few degrees reduced the performance so that it was only equal to, or less than, that obtained with no outer cowling. Nearly the maximum performance with any of the fuselages used on the *XF7C-1* could be obtained at any setting within the range of $-4°$ to $-8°$.

5. Changing the shape of the cowling in such a manner as to reduce either the quantity or the velocity of the cooling air at the cylinders impaired the cooling, but reducing the quantity improved the high-speed performance except for conditions when the cylinder temperatures were excessive.

6. The adding of low-drag cowling results in only a small improvement in the rate of climb.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *November 25, 1931*.

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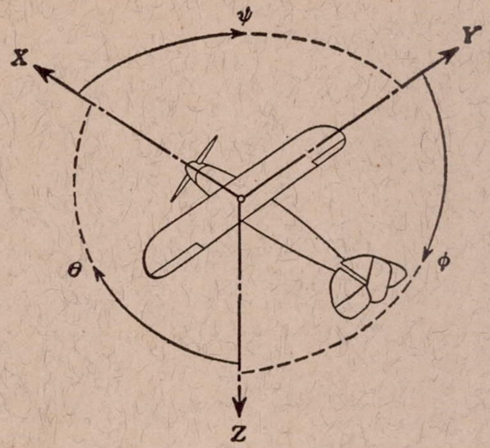

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	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

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

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

4. PROPELLER SYMBOLS

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

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.