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Dr. Lewis said 6-3-42 that "this
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PRELIMINARY MEMORANDUM

ANALYSIS OF THE AERODYNAMIC DESIGN OF THE P-47B AIRPLANE

By M. J. BREVOORT and GEORGE W. STICKLE

Langley Memorial Aeronautical Laboratory

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CLASSIFICATION CHANGE

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PRELIMINARY MEMORANDUM

ANALYSIS OF THE AERODYNAMIC DESIGN OF THE P-47B AIRPLANE

By M. J. BREVOORT and GEORGE W. STICKLE

INTRODUCTION

The subject airplane has several features which have an influence on its aerodynamic and cooling performance. The purpose of this memorandum is to relate the features peculiar to this airplane to its performance.

The P-47B airplane was designed by the Republic Aviation Corporation with a background of experience with a series of successful pursuit airplanes, the last of which were the P-35, XP-41, and the YP-43. The XP-41 airplane, of which only one example was built, was loaned by the Air Corps to the NACA in 1939 for a study of drag reduction possibilities, but a number of other investigations were added to the program. The full list of the work done at the Langley Memorial Aeronautical Laboratory follows:

(a) Drag analysis in the full-scale tunnel.

(b) Studies of influence of finish on airfoil sections in free flight.

(c) Reduction of visibility of exhaust flames and use of jet stacks for increasing thrust and speed.

(d) Study of ground-loop characteristics.

(e) Studies of cooling the R-1830 engine with two-speed mechanical-driven supercharger.

(f) Studies of flying qualities, particularly lateral control.

(g) Studies in body alinement with local air flow through a model in the 19-foot pressure tunnel with various wing sections.

(h) Studies in engine cowling to determine benefits of grouping air intakes.

(i) Studies to demonstrate the influence of afterbody length on the drag of fuselages and excrescences thereon.

These studies were the object of various reports prepared as memorandums conveying preliminary information as advance confidential memorandum reports. A list of these reports is given at the end of the paper.

When the Republic Company began the design of the P-47B airplane they consulted the NACA in regard to information obtained from the above projects. They were very much interested in the results of these investigations and seemed to make a real effort to incorporate the results into the development of the aerodynamic design of the new airplane.

In any new design there is generally a foundation of known and tested features and a few new features which constitute the advance in the art. With the references at hand, it is possible to discuss, one by one, those new features of the XP-47B airplane which are responsible for its performance and to trace their origin. The discussion of these features in subdivided under the following headings:

I. Body lines
II. Wing
III. Cowling
IV. Ducts
V. Cooling
VI. Aerodynamics of gun installation
VII. Stability characteristics
VIII. Propeller selection
IX. Range possibilities
X. Concluding remarks

I. BODY LINES

The body lines incorporated in this airplane were a compromise of experience of Republic, Army Design Handbood specifications, and information from tests at the NACA. Attention is called to certain particular features of these body lines that are of importance in regard to aerodynamic performance, and which might not be noted by a casual observation of figure 1, particularly the wing and body alinement and the shape of the afterbody.

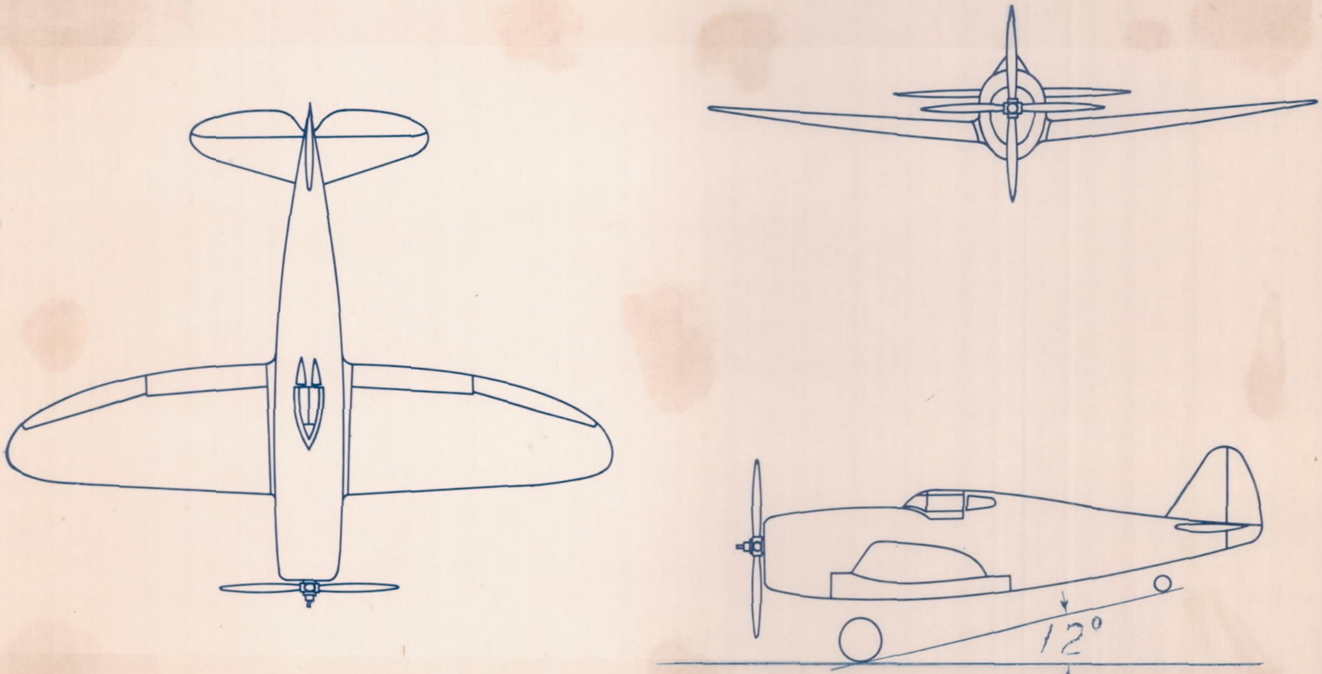

Figure 1. Body lines of P-47B airplane.

(a) The maximum width of the fuselage is maintained all the way back to the trailing edge of the wing. The usual contraction of the body that so often begins just behind the engine location and tapers to the tail of the airplane has been carefully avoided. This design eliminates the usual double expansion of the air at the juncture of the wing and body (one expansion caused by the contraction of the wing and one caused by the contraction of the body). This design helps make the flow in the wing-fuselage juncture as stable as the flow over the remainder of the wing, and thus helps prevent a breakdown of flow in this region. A breakdown of flow in this region is often evidenced by tail buffeting and poor tail effectiveness near the stalling speed of the airplane. This design adds some wetted area to the fuselage, but the advantages gained by stabilizing the flow and eliminating pressure drags far outweigh the disadvantage of more area for skin friction drag. This fact was experimentally demonstrated by a critical analysis of the data in reference 24.

(b) The fuselage afterbody (the portion aft of the master section, in this case, from the trailing edge of the wing to the end of the rudder) is four (4) times the maximum width and three (3) times the maximum height (leaving out the canopy over the cockpit). As was shown in reference 12, the afterbody of a fuselage may be likened to the expansion region of a venturi tube. If the expansion region is too short the energy loss in the venturi is high due to poor conversion of kinetic energy into pressure energy, and if the expansion region is too long the energy loss in the venturi is high because of skin friction on the sides of the venturi. The energy loss in the venturi is comparable to the energy loss in the flow over a fuselage; if the afterbody is too short the drag is high due to pressure drag; and if it is too long the drag is high due to skin friction. As pointed out in reference 12, it is necessary, however, always to make a fuselage in the presence of a wing longer than would be necessary for minimum drag for a fuselage alone, because the wing tends to make the flow follow a direction different from the axis of the body.[1] The reason for excluding the canopy in the calculation of the vertical expansion ratio is because the wing directs the flow downward over the rear of the fuselage and consequently the top side, on which the canopy is located, is the most neutral portion and does not affect the effective expansion ratio. The addition of the cockpit canopy in reference 12 furnished an experimental check on this point.

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[1] A body that has the proper alinement and expansion ratio to have low drag and be insensitive to small changes in body shape is called in this report a neutral fuselage.

(c) The fuselage was alined with the flow over the wing by lowering the ground angle from 16° to 12°. The alinement of the wing and the fuselage of an airplane is determined by the required ground angle. As pointed out in reference 2, a low-wing monoplane requires a lower ground angle for minimum drag than a high-wing monoplane, because the juncture of the wing and the fuselage is on the critical expansion side of the fuselage. The choice of 12° for the ground angle was a compromise between the angle required to give 90 percent of maximum lift without flaps, 16°, and an angle of 9° as recommended in reference 2. The choice of 12° proved a fortunate selection because the ground looping of the P-43 was cured by a reduction of the ground angle from 16° to 12° and consequently the P-47B as originally designed was free from ground-looping troubles.

<u>Tests on body lines</u>. - Five models were tested in references 12 and 24. Four fuselage shapes using two types of cowlings were tried and these were combined with two wings.

(a) A 0.4-scale model of the P-41 airplane.

(b) The P-47B type fuselage. This was the <u>only model tested</u> that was designed with sufficient room to internally house and cool the required equipment of the P-47B airplane.

(c) A 0.4-scale model of P-41 airplane with NACA 66-67 wing.

(d) Minimum wetted area fuselage with short afterbody.

(e) Minimum wetted area fuselage with long afterbody.

The test results on these fuselage shapes provide a basis for valuable conclusions.

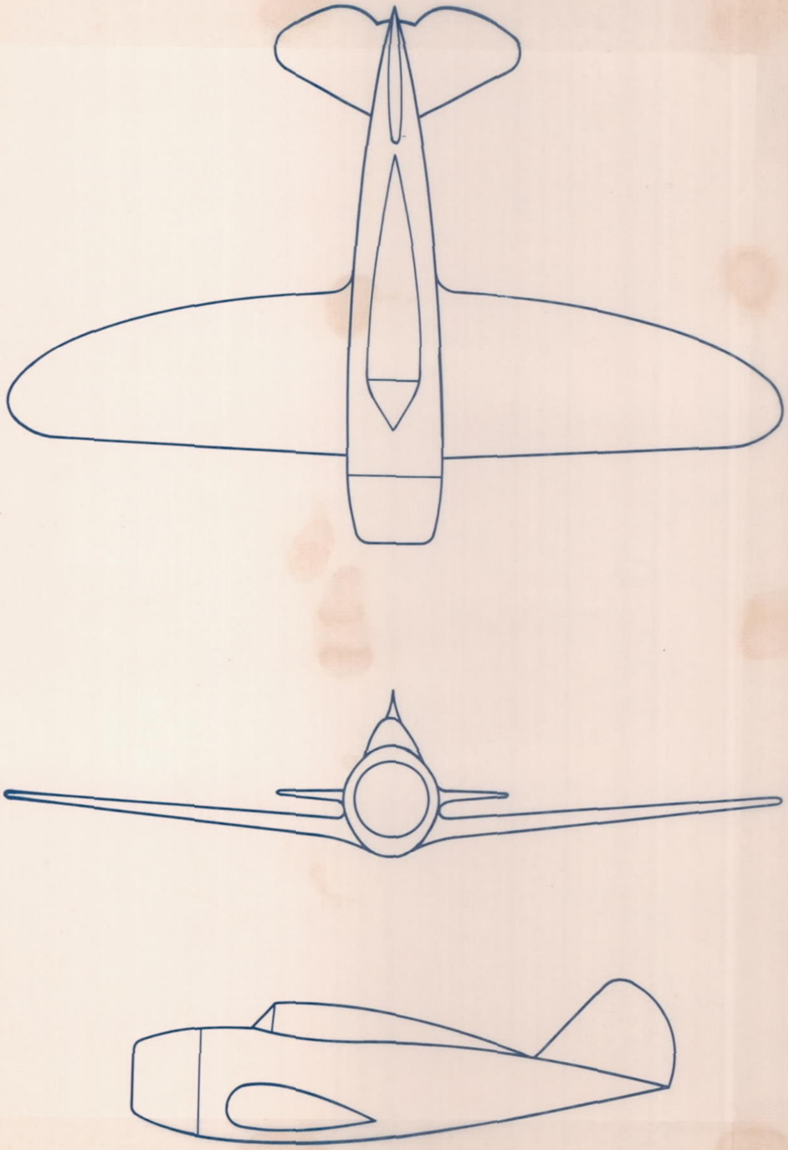


Figure 2. Four-tenths scale model of P-41.

(a) This model was built with provision for air flow through the engine but without provision for carburetor air intake or intercooler air intake. This model is a standard with which a number of later revisions are compared. The cross-sectional area of the fuselage at the center line of the engine for the full-scale airplane, of which this was a model, was 14.7 square feet.

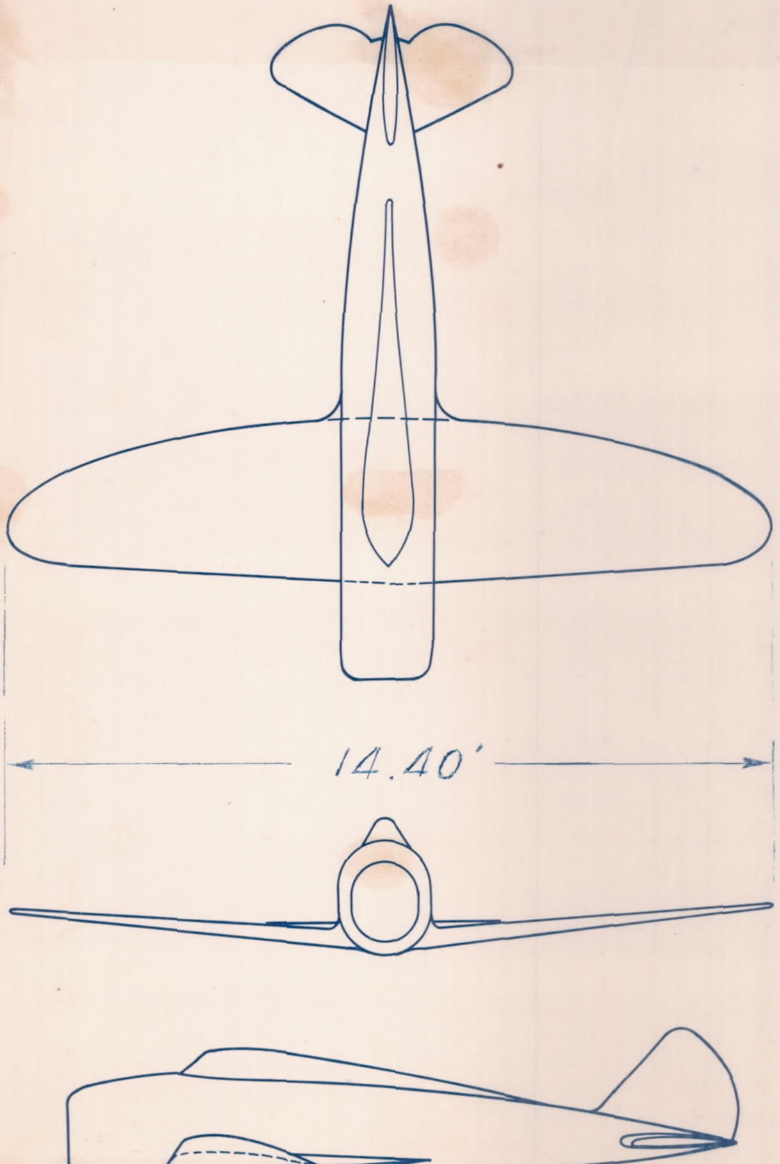


Figure 3. P-47B type fuselage.

(b) This model was built and tested with sufficient air flow for the engine cooling, the carburetor air intake, the oil cooler, and the intercooler. It provided room for the air intakes to carburetor, intercooler, and oil cooler by enlarging the area at the center line of the engine corresponding to full scale from 14.7 square feet to 18.5 square feet. As may be noted by the layouts, the ground angle was greatly reduced to permit alinement of the flow over the fuselage with that over the wing. The reduction of the ground angle combined with the elliptical cowling nose gives the fuselage approximately the same camber as the wing. The expansion of the air in the wing-fuselage juncture was kept equal to that over the wing itself by maintaining the maximum cross-sectional area of the fuselage all the way back to the trailing edge of the wing.

The drags in the varnished condition, from reference 12, of models (a) and (b) were both equal to $C_D = 0.0148$ based on the wing area. Model (a) had a total surface area of 136.3 square feet and model (b) had a total surface area of 147.5 square feet. Each had a wing area of 35.8 square feet. The surface friction coefficient as used by the Materiel Division of the Army Air Corps (reference 26) based on total surface area becomes for model (a)

$$C_f = C_D \frac{\text{Wing area}}{\text{Total surface area}} = 0.0148 \times \frac{35.8}{136.3} = 0.00388$$

and for model (b)

$$C_f = 0.0148 \times \frac{35.8}{147.5} = 0.00359$$

When the models were polished by the use of no. 400 water sandpaper, the drag was reduced on model (a) to $C_D = 0.0138$ and model (b) to $C_D = 0.0144$. These values give surface-friction coefficients of $C_f = 0.00362$ for model (a) and $C_f = 0.00349$ for model (b).

The higher surface-friction coefficient for model (a) is rather surprising since the coefficient for model (b) includes the elliptical nose opening with sufficient cooling air flow for the engine and all of the accessories while the coefficient for model (a) includes the requirements for the engine alone. The above fact demonstrates that the better alinement and more neutral expansions on model (b) lower the surface-friction coefficient. Since a complete airplane of a given type must enclose approximately the same volume to house the necessary equipment, a reduction of the surface-friction coefficient is a good criterion as to excellence of performance.

c. The NACA wing of 66 and 67 family was next fitted to the original P-41 model fuselage. The minimum drag coefficient in the polished condition was found to be C_D x 0.0112 based on the wing area of 42.83 square feet. The surface area of this model was 147.7 square feet, giving a surface-friction coefficient of:

$$C_f = 0.0112 \frac{42.83}{147.7} = 0.00325$$

This low friction coefficient is partly the effect of more relative wing area and partly the effect of a lower drag on the wing itself. A comparison of the results with the propeller operating, however, raises the drag of the model with the NACA wing while it has little effect on the original P-41 model wing. This difference in propeller action raises the drag coefficient from $C_D = 0.0112$ to $C_D = 0.0122$ making a $C_f = 0.00354$.

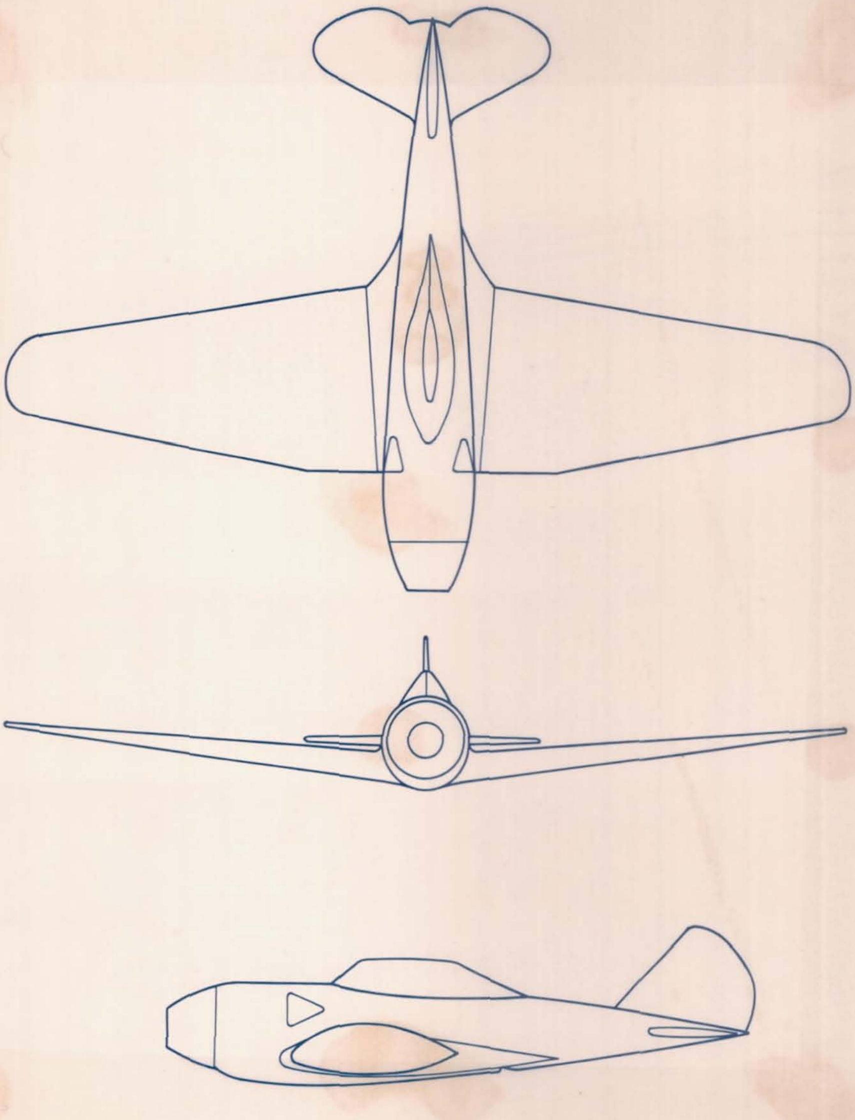


Figure 4. Minimum wetted area fuselage with short afterbody.

(d) The minimum wetted area fuselage with short afterbody was designed to reduce the wetted area to a minimum maintaining the same engine frontal area. A small model of this design was tested in the NACA 7- by 10-foot tunnel to minimize the peak pressures over the wing-fuselage juncture. As may be seen from the sketch, figure 4, the body reduces in cross-sectional area all the way from the engine diameter to the tail. This was done to decrease the wetted area in an attempt to reduce the drag. Comparing figures 3 and 4, it can be seen that the double expansion of the air in the wing-fuselage juncture caused by contracting both the body and the wing in figure 4 is carefully avoided in figure 3 by maintaining the body area back to the trailing edge of the wing. This difference in the afterbody treatment should be kept in mind in interpreting the results.

The drag of this model in the polished condition without the propeller was $C_D = 0.0112$. The wetted area of the model was 138.4 square feet giving a surface-friction coefficient of

$$C_f = 0.0112 \frac{42.83}{138.4} = 0.00347$$

which directly compares to the value of $C_f = 0.00325$ for the original fuselage on the same wing, an increase in C_f of 7 percent. This increase in C_f must be attributed to a greater pressure drag that may be caused by the double expansion in the wing-fuselage juncture. The fact that no benefit was obtained by this change illustrates the difficulties often encountered when a pressure drag determines the results of a change that at first looks to be beneficial. This result also demonstrates the practicability of a design that used the methods of model (b) to eliminate the sensitivity to small changes.

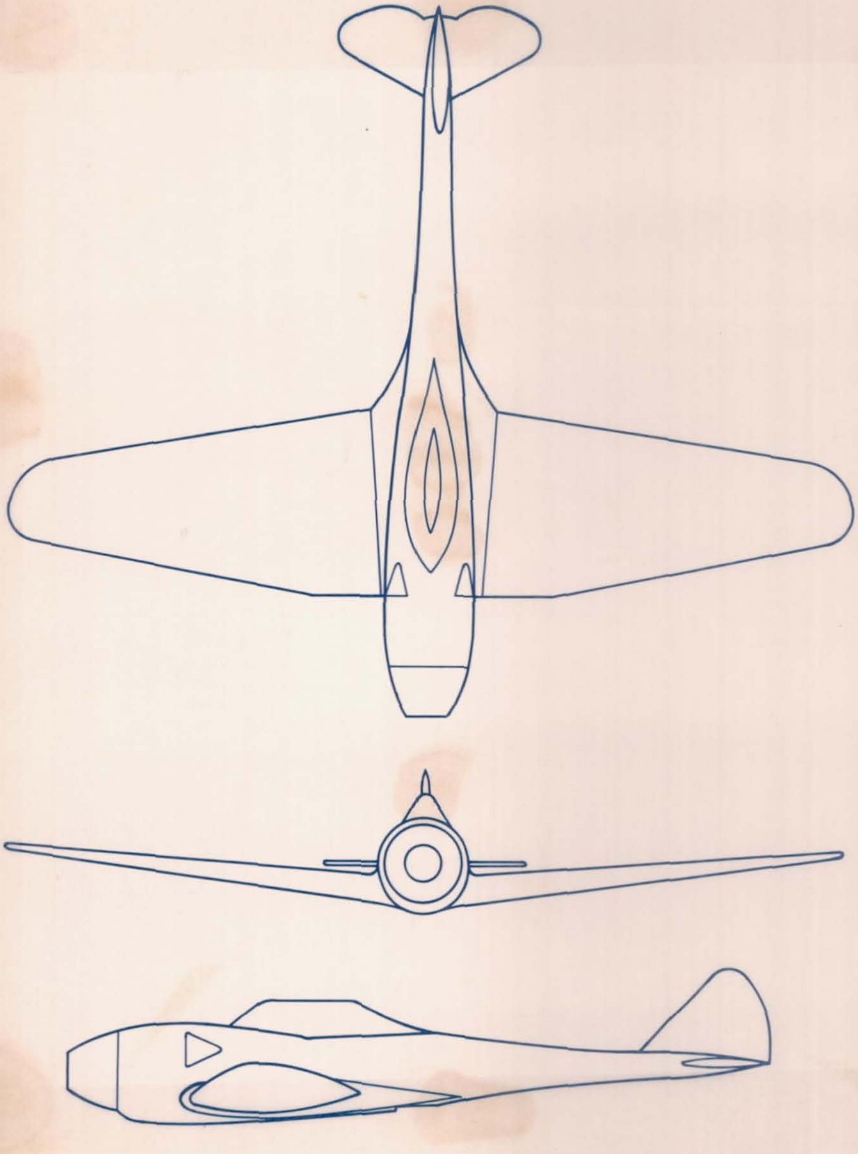


Figure 5. Minimum wetted area fuselage with long afterbody.

(e) This model was designed to determine the effect on the drag of a decrease in the size of the tail surfaces and obtaining the airplane balance by extension of the fuselage to give the tail surfaces a longer lever arm. Later tests have shown that this is not a satisfactory means of obtaining stability and that the longer lever arm is in some measure counterbalanced by the increased unstable moment of the fuselage. The drag of the complete model with air flow was $C_D = 0.0113$ at a lift coefficient of $C_L = 0.10$. The surface area of this model was 139.4 square feet, which gives a surface-friction coefficient of $C_f = 0.00347$ which is exactly equal to that of model (d).

(e) Concluding remarks: The P-47B type fuselage is the best adapted to the high altitude air-cooled pursuit-type airplane.

1. The fuselage is of ample size to enclose the equipment necessary for high altitude operation in a simple streamlined body.

2. The single cooling-air inlet in the nose of the cowling is of ample size to provide all of the cooling air.

3. The drag increase for the cooling-air inlet is negligible. This is accomplished by proper cowling design and the use of a neutral fuselage. (See footnote, page 6.)

4. The complete model drag based on surface area is comparable to the turbulent skin-friction coefficient of flap plates at the same Reynolds number.

II. WING

The wing selected for this airplane is a Republic development. Analysis of this wing section shows that the ideal angle of attack of the wing coincides with the high-speed level-flight condition at the design altitude for the present airplane. The thickness and the location of the maximum thickness along the chord insure that the wing will be free from compressibility losses for all level flight conditions. Analysis shows the camber, camber distribution, and thickness distribution to be nearly optimum. Analysis shows also that the wing will give low drag in the high-speed condition of flight for a wing surface roughness that is mechanically possible for present-day mass production.

The center of pressure travel with respect to changes of angle of attack has been found to be small, making the required tail area for control throughout the flight range reasonable. An analysis shows that the aspect ratio is nearly optimum for the loading conditions, load factors, and wing thicknesses employed in the design. The plan form is reasonably close to the optimum.

Wing tests. - The following combinations of wings and bodies were tested:

(a) The Republic wing on the original P-41 model. (See fig. (2).)

(b) The Republic wing on the P-47B type fuselage. (See fig. (3).)

(c) The NACA 66-67 wing on the original P-41 model.

(d) The NACA 66-67 wing on the short fuselage. (See fig. (4).)

(e) The NACA 66-67 wing on the long fuselage. (See fig. (5).)

The models were all 0.4 scale models. The Republic wings had an area of 35.8 square feet and the NACA 66-67 wing an area of 42.83 square feet. These models were all polished to an aerodynamically smooth finish. The tests were made in the NACA 19-foot pressure tunnel through a range of Reynolds number from 2.5×10^6 to 6.0×10^6.

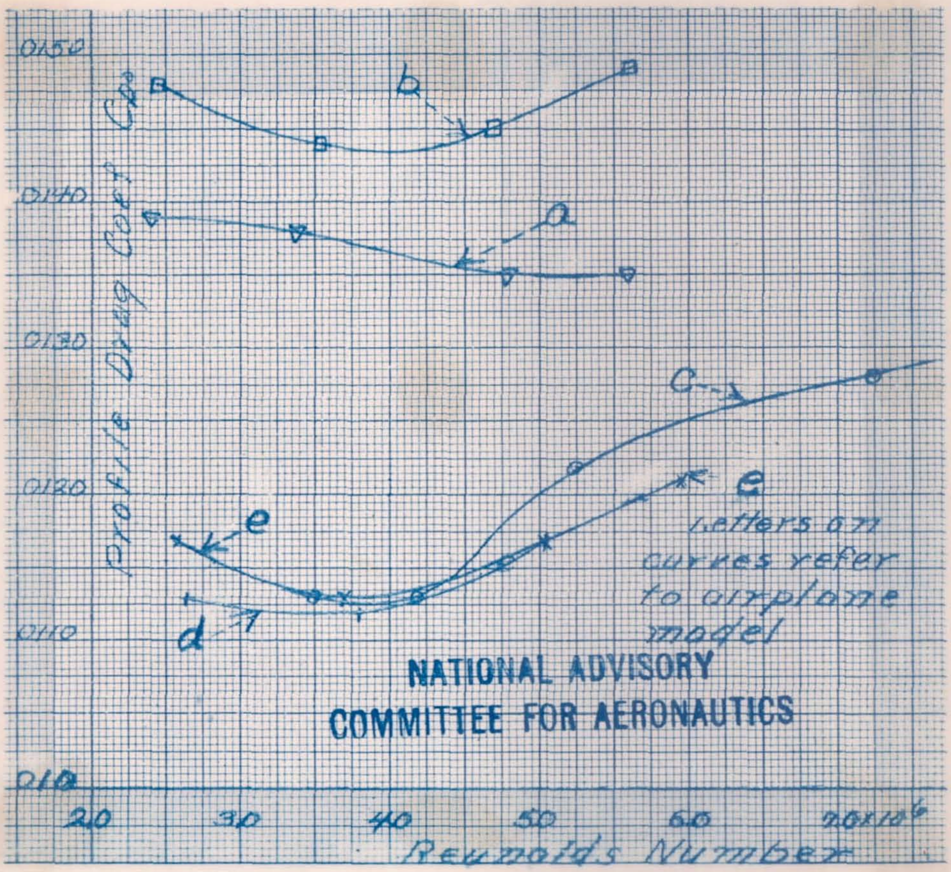


Figure 6. Profile-drag coefficients against Reynolds number for the five models.

Figure 6 shows the drag-coefficient curves for the five models listed above. These curves are characteristic of tests on all models tested in the tunnel. The minimum point on the curve is determined by the wind-tunnel turbulence, finish of the body, and the body shape.

As pointed out in an earlier section, the models listed above have various wings and bodies. A drag coefficient based on wing area may be quite misleading.

A drag coefficient based on total surface area, as introduced by the Materiel Division (reference 25), shows more nearly the true picture in regard to actual aerodynamic cleanliness.

The results presented in figure 6 have been recomputed to put the drag coefficient on the basis of surface area and are shown in figure 7. It is interesting to note that on this basis all the models have essentially the same drag coefficient.

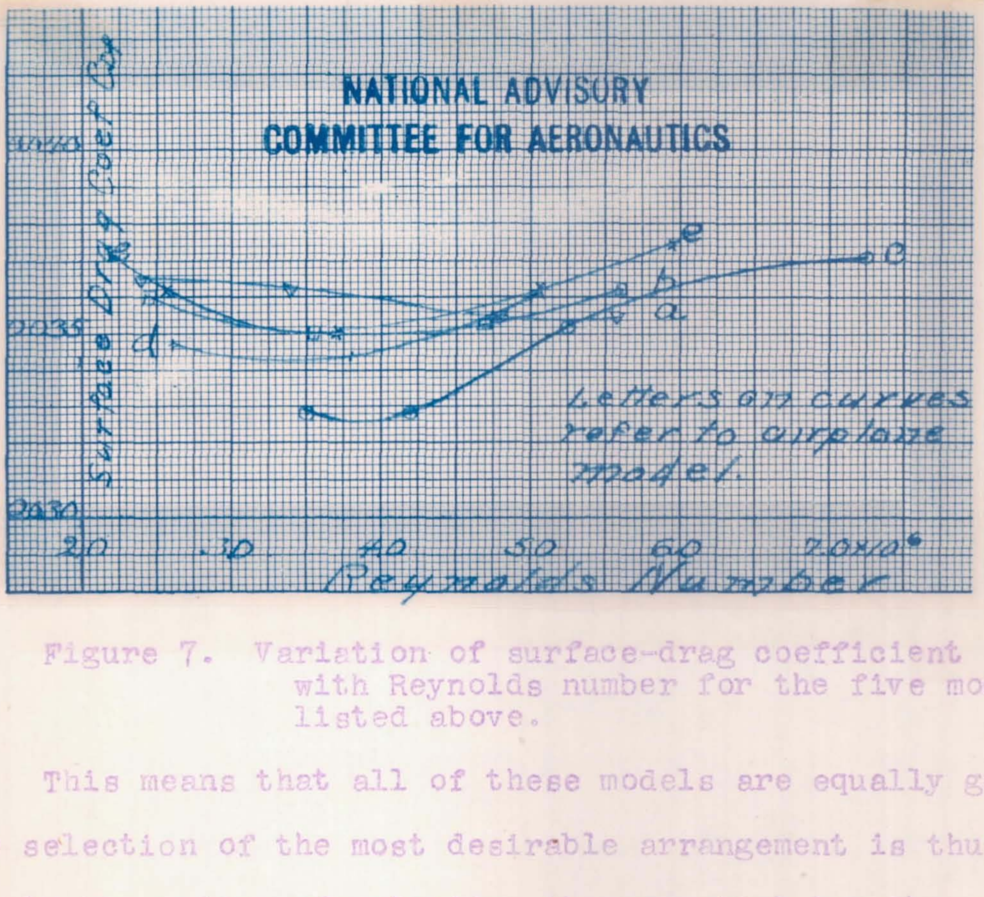


Figure 7. Variation of surface-drag coefficient with Reynolds number for the five models listed above.

This means that all of these models are equally good. The selection of the most desirable arrangement is thus simply the matter of selecting the one which has the physical characteristics which will accommodate the pilot, armament, gas supply, supercharger, intercooler, and provide the necessary air for cooling.

An analysis of the five models listed above has been made on the basis of these force measurements. The drag coefficients chosen for this analysis are the minimum values occurring in figure 6 regardless of the Reynolds number.

					Propellor Operating	
Model number	Figure number	Wing type	C_D at C_L = 0.10	C_D at C_L = 0.10 for wing area 35.8 square feet	C_D at C_L = 0.10 S = 35.8	C_D based on (volume)$^{2/3}$ for C_L = 0.10 S = 35.8
a	2	Republic	0.0137	0.0137	0.0137	0.0536
b	3	Republic	.0144	.0144	.0144	.0482
c	-	NACA 66-67	.0112	.0125	.0136	.0507
d	4	NACA 66-67	.0112	.0125	.0136	.0566
e	5	NACA 66-67	.0113	.0126	.0137	.0570

The above table presents the drag coefficients of the models listed above without propeller operating.

Column 1 refers to the models listed above. Column 2 gives the type of wing employed on the model. Column 3 gives the drag coefficient for the complete model.

Column 4 gives the drag coefficient of the complete model assuming that each model had a wing area of 35.8 square feet. Local wake surveys were made behind the wing. From these surveys the drag coefficients of the Republic and NACA 66-67 wings were found to be 0.0070 and

0.0042, respectively. By means of these drag coefficients the values in column 4 were computed.

Column 5 shows the drag coefficient of the model corrected to a wing area of 35.8 square feet and corrected further to allow for the increased drag due to the turbulence in the propeller slipstream. Here it is assumed that 40 percent of the wing is in the propeller slipstream. Tests (reference 24) showed that the NACA 66-67 wing in the propeller wake had an increase in C_{D_o} from 0.0042 to 0.0070.

Column 6 shows the drag coefficient based on the volume to the two-thirds power. Inasmuch as an airplane must be designed to have a certain volume to house the necessary equipment, volume is an important parameter. The arrangement resulting in the least drag for a required volume is an important consideration.

The table shows four drag coefficients for each model. Each is a true picture of the drag. Each, however, views the drag picture from a different angle, and accordingly allows the selection of the characteristics which gives the most desirable compromise.

Gun installation is considered under a separate heading and will only be considered here in connection with its effect on the wing performance. Tests (reference 24) showed that when the gun barrels extended ahead of the wing or when an opening was made in the wing large enough to accommodate the gun, the flow over the part of the wing behind the guns will be turbulent.

On the Republic wing the increase in C_D due to the addition of eight guns is about 0.0002 and on the NACA 66-67 wing about 0.0008 (both increments based on the total wing area).

The maximum lift coefficients for both the Republic and NACA wing were about the same. The Republic wing and NACA wing had C_D maximum of 1.63 and 1.61 with 0° flap and 2.13 and 2.12 with 60° flap, respectively. At other flap angle settings the agreement was of the same order.

Wing fillets were studied extensively throughout the test program. The revised model (fig. 3) having the Republic wing was found to require no fillet. It is believed that in this model the alinement between the wing and body was so nearly correct and that the juncture was so free from double expansion that in the normal high-speed flight condition the flow followed the wing-body juncture.

A comparison of wake surveys over the wing span indicated that the Republic wing on the revised model had a much lower momentum loss at the wing-body juncture than any of the other wing-body combinations tested. In fact, the NACA 66-67 wing tended to have such a high loss at the wing-body juncture that the integrated loss over the span was as large as that for the Republic wing. The same general tendency also appeared at the wing tip.

Considerable effort was made to reduce these momentum losses by changes in the wing section and wing fillet. These changes only resulted in very minor reductions in the loss.

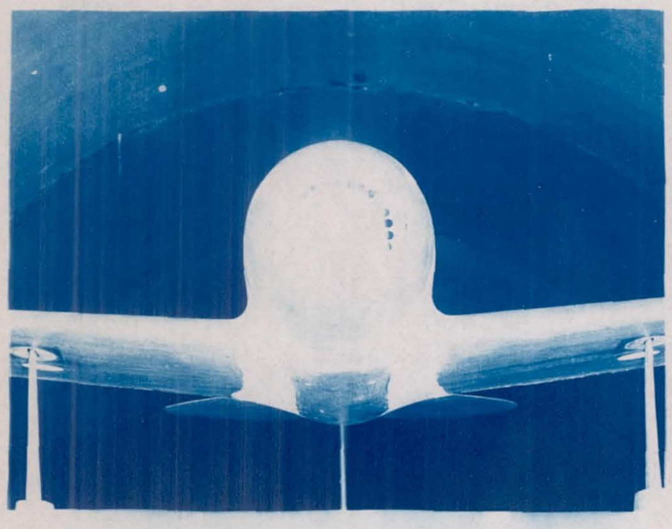
Concluding remarks. - The Republic wing selected for the P-47B exhibited good flying qualities both from wind-tunnel tests and flight tests on the P-41 and P-43 airplanes.

The drag coefficient is equal to that given by turbulent skin friction. The maximum lift of 1.63 compares favorably with other wings tested in this tunnel.

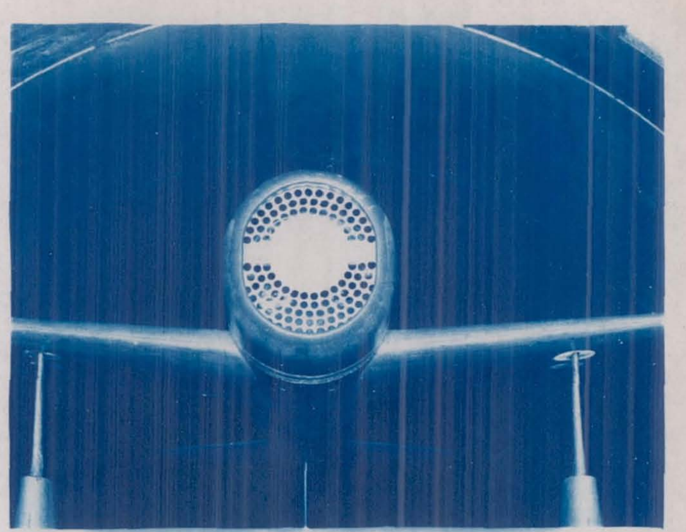
III. COWLING

The cowling selected for the airplane is a conventional NACA cowling with an elliptical shape to provide room beneath the engine for a single large duct to furnish air to the intercoolers, oil coolers and engine air intake. The selection of this cowling was based on the experience of the Republic Company with the P-43 and the results of wind-tunnel investigations described in references 2, 12, 22, and 24.

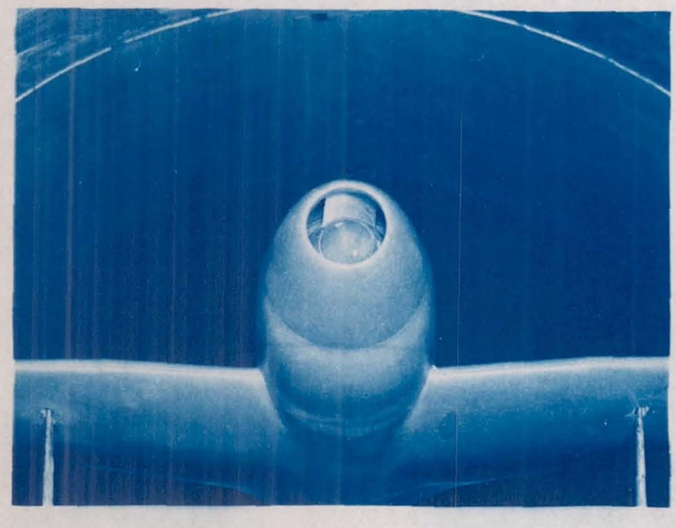
Four types of cowling were studied in references 12 and 24: (1) the conventional NACA cowling with circular opening in the front, (2) the elliptical cowling used on the P-47B, (3) the high-speed cowling tested with the spinner stationary,



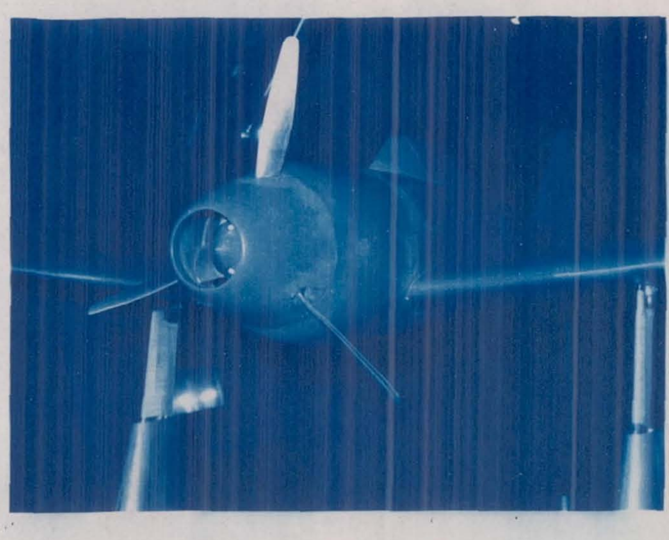
CONVENTIONAL NACA



ELLIPTICAL NACA



HIGH SPEED NACA



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The conventional and the elliptical cowlings differ in the frontal area of the cowling at the center line of the engine. The elliptical cowling is large enough to accommodate a large duct beneath the engine to provide air for cooling the accessories, intercooler, oil cooler, and providing air for the engine. The drag of the two cowlings with equal air flow was found to be the same and nearly equal to the drag of a streamlined nose plus the drag increment chargeable to the internal work done through the baffle.

The elliptical and the high-speed cowlings require a more elaborate analysis to determine which would be superior for application to the P-47B airplane. An analysis of the air requirements for the P-47B for various altitudes and attitudes for the condition of normal power of 1675 horsepower is given in the first five columns of the following table. The normal power rating was used in the analysis because the military power rating is a limited time rating with higher allowable temperatures and does not represent steady conditions.

1675 horsepower with Army air and average head temperature of 410° F.	1 Speed, miles per hour	2 Dynamic pressure, pounds per square foot	3 Pressure drop required, pounds per square foot	4 Pressure drop / dynamic pressure	5 Volume of air, cubic feet per minute	P-47B Cowl 6 Velocity in cowl entrance, miles per hour	7 Entrance velocity / airplane speed	8 q of entrance velocity / q of airplane velocity	High-speed cowl of ref. 24 9 Velocity in cowl entrance, miles per hour	10 Entrance velocity / airplane speed	11 q of entrance velocity / q of airplane velocity
Level flight S. L.	307	256	57	0.23	31,900	40	0.13	0.017	95	0.31	0.096
Climb at max L/D S.L.	175	80	53	.66	31,900	40	.23	.052	95	.54	.303
Climb at max Cooling S.L.	150	58	53	.91	31,900	40	.27	.073	95	.63	.400
Level flight at 27,000 ft	403	189	66	.35	66,500	84	.21	.044	200	.50	.250
Climb at max L/D at 25,000 ft	260	80	61	.76	60,900	77	30	.090	185	.71	.504
Climb at max Cooling at 25,000 ft	233	58	61	1.05	60,900	77	.33	.109	185	.79	.63

It should be noted that the ratio of pressure drop to the dynamic pressure varies from 0.23 to 1.05, and the value of air flow varies from 31,900 cubic feet per minute to 66,500 cubic feet per minute. The elliptical and the high-speed cowlings are compared in the last six columns of the table.

The velocity in the entrance of the elliptical cowling varies from 40 to 84 miles per hour while the velocity in the entrance to the high-speed cowling varies from 95 to 200 miles per hour. The kinetic energy of the entrance stream varies as the square of the velocity, and therefore the large amount of kinetic energy in the high-speed cowling requires a very careful design to minimize the loss in converting kinetic energy into pressure energy. For the high-speed level-flight condition at 27,000 feet altitude, the energy per unit time is 37 horsepower for the elliptical cowling and 204 horsepower for the high-speed cowling. It is difficult if not impossible to make a venturi expansion perfect enough to keep the slow losses at these high speeds at a low value in the distance available ahead of the engine.

The cooling of the elliptical and high-speed cowlings may be compared by reference to the table. For the maximum cooling climb at 25,000 feet altitude, the ratio of pressure drop across the engine to the dynamic pressure is 1.05. This is nearly the maximum that is available from the entrance to the exit of the cowling with the use of cowling flaps. The pressure ratios of dynamic pressure in the cowling entrance to the air-stream dymamic pressure given in columns 8 and 11 are 0.109 for the elliptical and 0.63 for the high-speed cowling. If all the pressure in the entrance were lost in the elliptical cowling the total pressure drop across the cowling from entrance to the exit would be 1.16 q; and for the high-speed cowling, 1.68. Part of the entrance dynamic pressure will be converted into static pressure in both cowlings, but the necessity of a nearly perfect conversion in the high-speed cowling is apparent if satisfactory cooling is to be obtained.

The drag and compressibility characteristics of the high-speed cowling are dependent on the velocity ratio of the entrance. A low-drag and high-compressibility speed may be obtained for small range of entrance velocity ratios. Due to small radii that are demanded by internal and external flow both being important, a wide range of velocity ratios with good drag and compressibility characteristics is impossible. If the cowling is designed for an entrance velocity ratio of 0.5 for the high-altitude level-flight condition, it may be seen from the preceding table that at the low-altitude level-flight condition a velocity ratio of 0.31 is obtained. This lower velocity ratio will increase the negative pressure over the lip of the cowling and reduce the speed at which the external velocity will be in trouble due to compressibility. In the high-altitude maximum cooling climb condition the entrance velocity ratio has increased to 0.79 and the internal lip of the cowling becomes critical and makes an efficient conversion of the dynamic pressure into static pressure more difficult.

The drag and compressibility characteristics of the elliptical cowling are not dependent on the velocity entrance ratio because the external shape was made such that it would be neutral to zero air flow. This is possible because the internal shape is made unimportant by keeping the entrance velocity small by the use of a large area.

The blower cowling (reference 24) when designed for high-altitude climb imposes a serious penalty on cruising and low-altitude operation. Analysis of the conditions at the blades of the blower at altitude show that they would be set at approximately 45° with the thrust axis. Of this 45°, 38° is the angle of the relative wind inside the spinner and 7° is angle of attack.

At low altitude a similar analysis for level-flight condition shows that the lower velocity in the entrance of the cowling has reduced the angle of the relative wind down to 22° and increased the angle of attack including the inflow angle to 23°. In other words, the blower is loaded up for the low-altitude condition where cooling was already ample and unloads for the high-altitude condition.

These limitations of the blower cowling design of reference 24 were recognized and this design was tested only to study the effect of blower operation on the external drag. The chief reason for using a blower cowling is to permit an existing engine to be operated at an altitude above the altitude for which it was designed. In an actual installation the blower could be made so that it could be declutched by placing it behind the propeller or even behind the engine and thus eliminate the penalties due to operation at the wrong altitude. The use of a blower is only an expedient for correcting the design of an existing engine for rapid use; the obvious method that should be used for normal operation is the increase of the surface cooling area of the engine to eliminate the need of a complicated blower.

Power for cooling for the P-47B is to all practicable purposes only the useful work done in pumping the cooling air through the cooling equipment. It has been shown in references 12 and 22 that when a cowling of the C type is installed on a fuselage or nacelle with a neutral afterbody the drag is no more than that of a streamlined nose on the same body. These references show that the high drag sometimes associated with a conventional cowling is due to a critical afterbody shape and is not due to the cowling requirements.

Compressibility on all three cowlings was computed from pressure measurements on the cowling. The P-47B which has the lowest critical speed, has a critical speed of 440 miles per hour at 25,000 feet (reference 12), which is above the speed of the airplane. The high-speed and blower cowlings will be free from compressibility over the outside at much higher speeds.

Conclusions. - Four arrangements of cowling were considered for use in the P-47B airplane. The elliptical NACA cowling was selected because:

1. The pressure available for cooling is adequate in all design conditions.
2. The cowling is free from critical design features.
3. The power for cooling in the design condition is low (less than 5 percent of engine power at the critical altitude).

4. The critical compressibility speed is well above the design speed.
5. The cowling is simple and cheap to build.

IV. DUCTS

The ducts used on the P-47B for intercooler, oil cooler, and charge air are located on the underside of the airplane extending from just ahead of the engine to well back in the fuselage where the intercoolers and superchargers are located.

The ducts employed here were made with large cross-sectional area to reduce the air velocity in the ducts. In this way the losses are small due both to wall friction and duct turns. Accordingly, the pressure for cooling is high and the power for cooling is low.

If the increased duct size must be obtained by a proportionate increase in the frontal area of the fuselage, the optimum duct size may be obtained by equating the external power increase to the internal power saving. The external power increase is equal to C_DqFV, where C_D is approximately equal to 0.06 for well-faired increases in frontal area; q, the dynamic pressure of the air stream; F, the increase in frontal area; and V, the speed of the airplane. The internal power decrease is $Q(\Delta_{p_1} - \Delta_{p_2})$, where Q is the quantity of air flow and $(\Delta_{p_1} - \Delta_{p_2})$ is the change in pressure required to force the quantity Q through the two ducts. (See reference 21.)

V. COOLING

The cowling and duct system employed in this airplane guarantees adequate air with ample pressure differential for cooling the engine, oil coolers, and intercoolers.

Both the oil coolers and intercoolers are of sufficient size. The intercooler is especially good, being almost of optimum dimensions based on analysis following reference 23.

Reports from both the Republic and the Pratt & Whitney engineers indicate that the airplane will easily meet the Army cooling requirements. In fact, the intercooler cools the charge air to 85° F at an altitude considerably above the design altitude.

VI. AERODYNAMICS OF GUN INSTALLATION

The problem of fairing so many machine guns into a wing so that they do not cause large interference effects on the lift and drag of the airplane is very difficult. In tackling this problem the machine-gun barrel end was considered as a miniature open-nose cowling and the fairing conformed to the lines dictated by such considerations. The exits in the wings were again handled in the same manner since they were located approximately at the stagnation point of the wing. The openings were well rounded and faired to prevent separation of the flow due to too large accelerations of the air. The rounding of the edges of the wing opening and barrel-end fairing makes these parts as neutral to compressibility effects as the cowling nose. The effect of gun installations on wing drag is discussed under the heading of wing.

VII. STABILITY CHARACTERISTICS

The XP-47B was designed to have proportionally larger tail surfaces located further from the center of gravity than previous Republic airplanes. (See reference 5.) From studies made at the NACA on several airplanes and models including the P-41, it appears that this is a step in the right direction. There is no written information on the stability characteristics of the P-47B, but comments of pilots who have flown the airplane indicate that it is not sensitive or tricky in its control. The high performance of this airplane coupled with theoretical considerations shows that the high-speed penalty paid for these generous tail-surface areas is not exorbitant.

VIII. PROPELLER SELECTION

The subject of propeller selection for this airplane created more than usual interest because, at the time of its selection, the propeller for this airplane had to absorb more power at a higher altitude and a higher forward speed than any previous design. Computations based on wind-tunnel-test data showed the propeller efficiency would be reduced to 70 percent or below at the design critical altitude because of compressibility losses. Furthermore, the computations showed that the propeller selected should be nearly free from compressibility losses at 5000 feet altitude. These computations suggested testing the airplane at several altitudes and powers in order to check the computations in free flight.

Analysis of preliminary test data on this airplane indicate that the propeller efficiency reduction due to compressibility effects are surprisingly much smaller than expected for this propeller. If this preliminary analysis conveys the true picture of compressibility losses, then the difficulties encountered in designing a propeller for high altitude, high power, and high speed are greatly reduced.

IX. RANGE POSSIBILITIES

The mission of a pursuit airplane requires that the maximum performance of speed and rate of climb be obtained in the design. These two requirements are diametrically opposed to long-range possibilities, and, therefore, the range is usually a minimum. In order to use the pursuit airplane as a convoy pursuit, or to ferry the pursuit airplane great distances, it is often necessary to extend the range of the pursuit. This is often done by placing gasoline in streamlined tanks beneath the fuselage; and, because of the large interference effects of two streamlined bodies so close together, the drag of the airplane is sometimes doubled by the addition of the external tank.

Because of the extreme importance of extending the range of a pursuit airplane for ferrying and escort work when needed, the work of reference 21 was applied to the P-47B in reference 15. By the attachment of a temporary gasoline tank to the under side of the fuselage with a temporary streamlined fairing covering it, as shown in reference 15, the range of this airplane can be increased from 1800 miles to 3000 miles for the maximum L/D condition of flight. This range can be obtained with a reduction in top speed due to parasite drag of 10 miles per hour and a reduction due to induced drag at full load of 10 miles per hour. The addition of the gasoline tank would decrease the initial rate of climb at sea level from 3500 feet per minute to 2500 feet per minute. This reduction in the initial rate of climb might not be very important because for defense over the airdrome the ships without the extra gasoline tank could be used.

X. CONCLUDING REMARKS

The P-47B airplane is a good airplane because it incorporates features that have been tried and found successful in practice into an optimum design that avoided critical operational characteristics.

1. The cooling was made adequate and efficient by optimum cowling, duct, intercooler, and oil cooler design.
2. The fuselage was made large enough to inclose all the necessary equipment in a single streamlined body.
3. The wing-body juncture and afterbody were made free from large pressure drag by the elimination of double expansions, by proper alinement, and by the use of a neutral afterbody.

Each of these features contribute to the performance and reliability of the airplane.

The aerodynamic design of the P-47B airplane is an example of the successful application of all available information and experience into a desirable airplane. The Republic Company made use of model and flight tests on other airplanes to select the features for the P-47B. The fact that one of these models had, as one of the primary considerations in its design, the needs of the air-cooled engine at high altitude made the application somewhat easier. The aerodynamic design of the P-47B incorporated features throughout which were efficient and least critical in operation.

Design based on tests and experience is much more effective than the correction of faulty design by tests after the airplane has been built. In order for research to be effective it must be executed before the design is started, it must be made available to the designer, and be used by the designer. It is only in this way that airplanes of maximum performance and airplanes free from critical operation can be developed.

There exists at the NACA a power-plant installation group whose function is to bring a closer contact between industry and research, and thus make possible the incorporation of design requirements into research models.

Due to the national emergency in which our country finds itself, this field of applied research has a new and vital meaning. It should incorporate into new designs features that have been tried and found successful in practice, do it in such a manner as to give a design that is not critical to small changes in operating conditions, and seek maximum performance that is consistent with the first two considerations.

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