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3.3 Summary of Drag Clean-Up Tests in NASA Langley Full-Scale Tunnel

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Introduction

Before I start to describe the drag clean-up work in the Langley full-scale tunnel, let me recognize the pre-eminent work in the drag field. The late Sighard F. Hoerner in his book Fluid-Dynamic Drag (Ref. 1) has done a wonderful job of pulling together, organizing, and summarizing the vast and fragmented knowledge of aerodynamic drag. His book is the Bible on the subject. The book is vastly detailed in its presentation and references, and is about all one would need to work the drag problem for general aviation airplanes other than those that are pushing the drag-rise Mach number. Such high-speed aircraft are particularly subject to compressibility and interference problems which will be addressed by Mr. Thomas C. Kelly in his paper for the wing-drag session of this workshop.

It should be noted that Hoerner's book is not a "how-to" book. It does not set forth a design procedure. Any sensible aerodynamicist knows that airplanes are not designed for low drag alone. They must be designed to do their job (accommodate people, etc.); they must be designed for practical, economical manufacture; and they must be designed with enough sex appeal to sell. So Hoerner's book, in effect, tells how to get to the ideal shape, and the drag price for departing from that ideal shape. Thus it gives the drag information needed for trades of performance versus other requirements.

Potential in Drag Clean-Up

Now to get to the specific subject of this paper--the drag clean-up work in the full-scale tunnel. This work was done between 1935 and 1945 on W. W. II fighters and light bombers; so there is reason to question how applicable it is to today's general aviation airplanes. If it is applicable at all, it is obviously most applicable to the propeller powered airplanes. Since I am not very well acquainted with general aviation airplanes, I started out by making a few calculations that would let me see in terms of size, shape, and drag how some of today's general aviation airplanes compare with the small military airplanes that were the subject of the drag clean-up work.

Figure 1 presents a tabulation which resulted from these calculations. Here are compared certain characteristics of early W. W. II fighters and today's light twin general aviation aircraft. The figures given in each column are averages for five aircraft. These aircraft did not differ from the mean by more than ± 15 percent in any item. The W. W. II fighters selected were the cleaner of the 23 aircraft for which results are summarized in references 2 and 3. There are the P-40, P-41, P-51, P-63, and F4F. They are early models, if not prototypes, of these aircraft as can be inferred from the low gross weight. The light twins are those for which drag could be calculated from information given in a recent issue of Jane's All The World's Aircraft--that is, aircraft for which maximum speed was quoted at sea level or within the range of altitude for which supercharged engines were flat-rated. The calculated characteristics of the light twins are therefore no better than the information in "Jane's" or assumptions of 80 percent propulsive efficiency and 80 percent span efficiency factor with regard to drag due to lift.

Now let us trace through the figures and see what we can conclude. The two classes of airplanes have very nearly the same span and length. The light twins have 20 percent less wing area and 10 percent more wetted area, which factors would tend to cause their drag coefficient to be 30 percent higher than that of the fighters. On the other hand, they have only about one-half as much engine to cool which tends to offset one-third to one-half this difference. So, for equal aerodynamic cleanness we might expect the light twins to have 10 to 20 percent higher drag than the fighters. The figures show that the value of C_{D_o} (drag coefficient at zero lift) for the present light twins is indeed slightly higher than that of the fighters as received at the full-scale tunnel before the drag clean-up. Actually since the value of C_{D_o} for the light twins is only 10 percent higher than that of the fighters (as received), it would seem that they were slightly cleaner. (Before we go further, note that the measured values of C_{D_o} for the fighters have been corrected for Reynolds number effects from the 80 mph speed at which the tests were run to the 200 mph speed of the light twins.)

Let us continue by running down the rest of the drag figures for the fighters as received. The friction drag coefficient is that calculated on the basis of the wetted area, body and airfoil thickness, and a fully turbulent boundary layer. The cooling and parasite drag values are specifically those of the P-41 which will be discussed later. The figures for the cleaned up fighters show marked reductions in cooling and parasite drag. These reductions were achieved by reasonable changes which could be made on a practical operating airplane. The friction drag could not be reduced without impractical surface smoothing. But there was a substantial reduction in total C_{D_o}.

For the present light twins, the friction drag was calculated and was larger than that of the fighters because of the greater wetted area and because of the smaller wing area used as a reference. The cooling and parasite drag could not be separated. The last column indicates what the potential for drag clean-up might be. On the basis of the cleaned-up fighter data, the parasite drag might be similar to that of the fighter, the cooling power of the engines of only one-half the total power might be only one-half as great; and the total C_{D_o} might be reduced from 0.0255 to 0.0195. This is a 13 percent reduction which would result in a 4 percent increase in speed, or a 13 percent increase in range or reduction in fuel consumption at the same speed.

The foregoing figures are admittedly very rough, but they indicate enough potential for drag reduction to warrant pursuing the subject. Another conclusion that might be inferred from the drag figures for the light twin is that parasite drag can hardly be responsible for the high drag over and above friction drag; so there must be very substantial gains to be made in cooling drag.

Full-Scale Tunnel Tests

The remainder of this paper will examine some of the principal items in the W. W. II airplane drag clean-up work which accounted for considerable amounts of excess drag. And by the way, I have gone over general aviation aircraft in the NASA hangars, and at our local airport, and have found all of these items on current general aviation aircraft--not all on any one aircraft, of course. The total of all of them would make the value of C_{D_o} of the average light twin of Figure 1, 30 percent higher than that shown.

Drag Clean-Up Tests of a Representative Airplane

The procedure in the full-scale tunnel tests was to remove all the protuberances from the airplane, to seal all openings, and to fair obvious sources of drag such as a blunt sealed radial engine cowling. The drag of this sealed and faired airplane was measured and if there was any reason to suspect that it was unduly high, the trouble spots were sought with tufts, surface pressure data, and wake surveys and were then refaired to give a good basic shape. Such a sealed and faired condition for the XP-41 airplane is indicated in Figure 2.

As the seals and fairings associated with the powerplant installation were removed one-by-one, the drag of the following items was identified as show in Figure 3, the drag values being given in percent of the drag of the airplane in the sealed and faired condition:

Open engine cowling engine and exit to permit cooling air flow	18.6%
Unfaired carburetor airscoop	3.6%
Cooling airflow through accessory compartment	3.0%
Projecting exhause stacts and open hole through which they project	3.6%
Intercooler	6.6%
Oil cooler	10.2%

The total drag of these items associated with the power plant installation increased the drag 45.6 percent above that for the sealed and faired condition.

The drag for the additional features required to bring the airplane to service condition are shown in Figure 4 by the underlined numbers:

Removing seals from gaps in cowling flaps	5.4%
Opening case and link ejector chute	1.8%
Opening seals around landing gear doors	1.2%
Sanded walkway	4.2%
Radio aerials	4.8%
Guns and blast tubes	1.8%

The total drag of this group of protrusion, roughness, and leakage items equals 19.2 percent of the drag for the sealed and faired condition.

Look at what has happened to the clean airplane we started with! In order to make it useful we have increased its drag nearly 65 percent mostly by adding items that by themselves do not appear particularly large.

All of this drag, however, is not necessary . Additional tests and careful analysis showed that the drag of the power plant items could be reduced to 26.6 percent and the drag of the roughness and leakage items could be reduced to 2.5 percent, thus saving nearly 36 percent of the drag of the basic condition.

It is particularly important to note that in general those items have drags of only a few percent each. Yet, when taken altogether, they add up to an impressive total. We started with an airplane in Figure 1 that was exceptionally clean and in bringing it to a usable configuration unnecessary drag was added along with the drag associated with the necessary functions. The message here would seem to be that there is a lot to be gained from attention to details in aerodynamic design.

Design Features Contributing to Excessive Drag

The following selected examples illustrate some of the design features in which lack of attention to detail led to excessive drag.

Cooling drag - The first principles of reducing cooling drag are: do not take in too much air, keep the internal flow passages clean, and dump the air tangential to the surface in a streamwise direction. But look, in Figure 5, at what a difference details can make. An exhaust collect or ring, cowling-flap actuating linkage, and a sharp lip just inside the cowling flap outlet caused an increase in drag coefficient of 0.0007 which is 5 percent as great as the friction drag of the entire airplane.

Variable cowling outlet flaps are, of course, used to reduce cooling drag in high speed conditions; but look, in Figure 6, at what leakage through joints in the flaps can do if they are not sealed. High pressure air from inside the cowling squirts out normal to the stream causing an increase in drag of 4 percent of the airplane friction drag for this case. Such cowling leakage was a very common cause of excessive drag in the World War II airplane as received at the full-scale tunnel. It could probably be more properly classified as leakage drag than cooling drag, but in this paper I have chosen in most cases to relate leakage drag to the functional item with which it is associated.

Engine exhaust stacks - It would seem that exhaust stacks if properly recessed or faired and turned rearward would cause virtually no external drag, but improper treatment of exhaust stacks can result in large amounts of drag as shown in Figure 7. The installation shown at the top of the figure appears very similar to the treatment of the exhaust nozzles of turboprop engines in some of today's general aviation airplanes; and it caused an increase in drag corresponding to 16 percent of the friction drag of the entire airplane. The installation shown at the bottom of the figure does not protrude into the stream, but caused a drag increase of 8 percent of the friction drag because the exhaust gases and the cooling air coming out the hole around the exhaust stacks were ejected almost normal to the airstream.

It is also evident from such installations that designers sometimes fail to take advantage of the considerable thrust the exhaust gases can affort if directed rearward. I do not have data for today's general aviation engines, but based on the exhaust gas thrust per horsepower of World War II fighter engines, I would expect the thrust coefficient $(\frac{T}{qS})$ of the average light twin of Figure 1 to be 0.0026 at full power and a speed of 200 knots. This is enough thrust to offset 15 percent of the friction drag of the airplane.

Landing gears - Even retractable landing gears can have considerable drag if not properly treated. Figure 8 shows that the fully faired landing gear shown at the top of the figure had a drag of 7 percent of the friction drag when the seals over the joints were removed. This drag was caused by air leakage through the 1/8-inch cracks around the coverplate. Removal of the rear door to expose half the wheel resulted in an additional small (2 percent C_{D_f}) increase in drag. This result, that failure to seal the landing gear doors caused considerable drag, was found repeatedly in the drag clean-up tests.

Control surface gaps - Figure 9 indicates that tail surface gaps can cause an increase in drag of about 5 percent of the friction drag--and it would seem that the ailerons could cause an additional 2- to 3-percent increase. Such control surface drag can result from several sources. Air can leak through unsealed gaps from the high pressure side of the surface to the low pressure side where it can exhaust normally to the stream as a jet spoiler. The base drag of the blunt rear of the fin or stabilizer can cause considerable drag, both directly as base drag and additionally, by pumping air through the airframe if there are lightening holes in the rear spar. Hoerner indicates that such base drag can be reduced markedly, in fact the drag of the entire tail can be reduced nearly 20 percent by reducing the thickness of the airfoil at the blunt base of the fixed surface about 10 percent so that it is thinner than the maximum thickness of the control surface.

Irregularities and leakage - Figure 10 shows the results of irregularities and leakage in one small area of a wing which had a fold joint and a number of access panels. Probably very few general aviation airplanes have features corresponding to the wing-fold joint, but the total number of doors and access panels might be even larger than for this case. In any event, most drag of this type can be eliminated by better fitting and by elimination of air leakage.

Walkways - Figure 11 shows the drag coefficient of a sanded walkway to be 0.0010, or 8 percent as great as the friction drag. This is an extreme case because the walkway protruded about 1/4-inch above the wing surface. But, even for more representative cases, the walkway drag was two-thirds this great.

Conclusions

It would seem that two general conclusions might be drawn from the foregoing analysis and examples.

1. There is probably considerable possibility for marked reductions in the cooling drag of general aviation airplanes with reciprocating engines.
2. Careful attention to detail design and fabrication can result in substantial reductions in drag.

References

1. Hoerner, Sighard F., Fluid Dynamic Drag, published by the author, 1958. Library of Congress Caralog Card No. 57-13009.

2. Dearborn, C. H., and Silverstein, Abe, Drag Analysis of Single-Engine Military Airplanes Tested in the NACA Full-Scale Wind Tunnel. NACA Wartime Report ACR, October 1940.

3. Lange, Roy H., A Summary of Drag Results from Recent Langley Full-Scale-Tunnel Tests of Army and Navy Airplanes. NACA ACR No. L5A30, 1945.

	EARLY WWII FIGHTER+		LIGHT TWIN+	
SPAN	37		39	
L.O.A.	31		32	
WING AREA	240		200	
WETTED AREA	950		1050	
HORSEPOWER	1100		560	
T.O. WEIGHT	7100		5700	
	AS RECEIVED	CLEANED UP	PRESENT	POTENTIAL
C_{D_o}	.0225*	.0175*	.0255	.0195
$C_{D_{friction}}$	.0130	.0130	.0170	.0170
$C_{D_{cooling}}$	.0070	.0040	} .0085	.0020
$C_{D_{parasite}}$	.0025	.0005		.0005

+AVERAGE OF FIVE AIRCRAFT EACH.
MAX DEVIATION FROM MEAN = ±15%

*CORRECTED TO SAME SPEED AS LIGHT TWIN

Figure 1. Drag Comparison

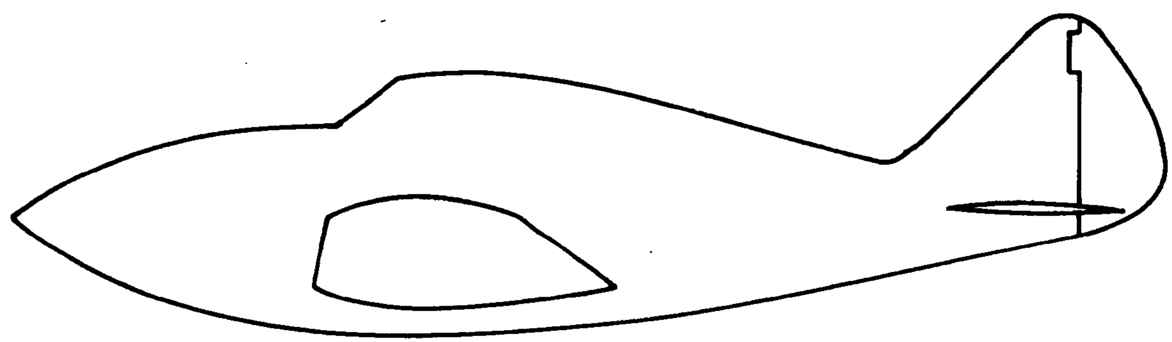
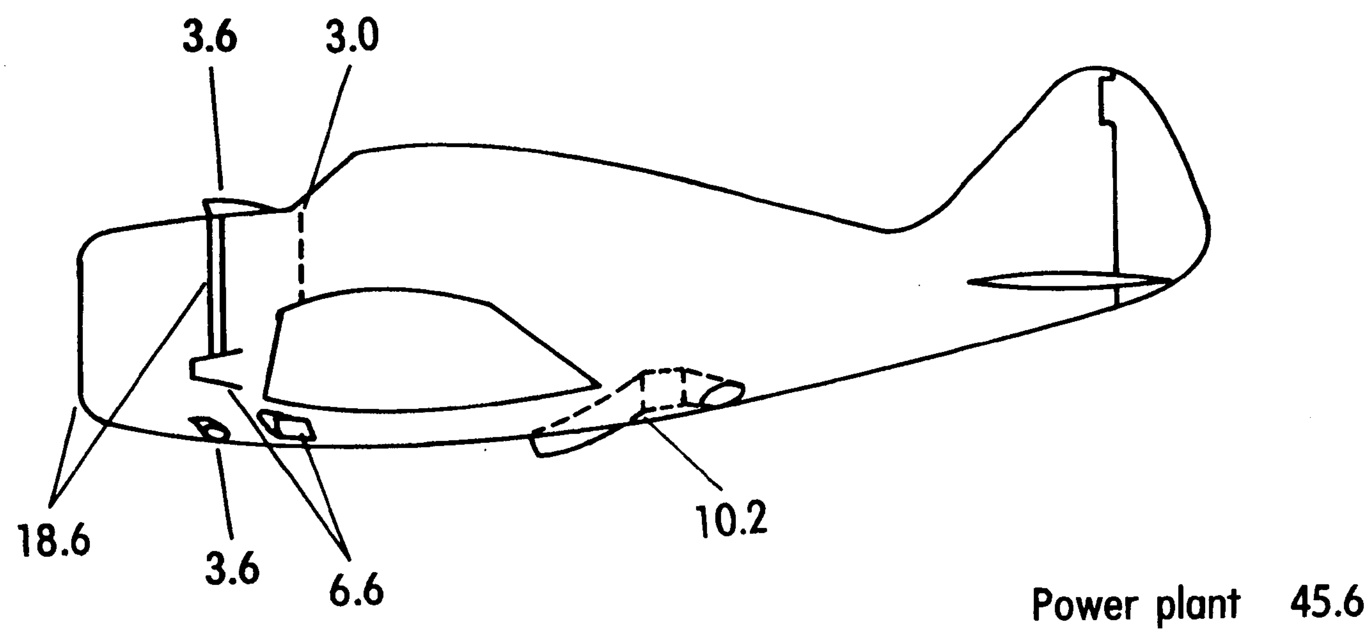
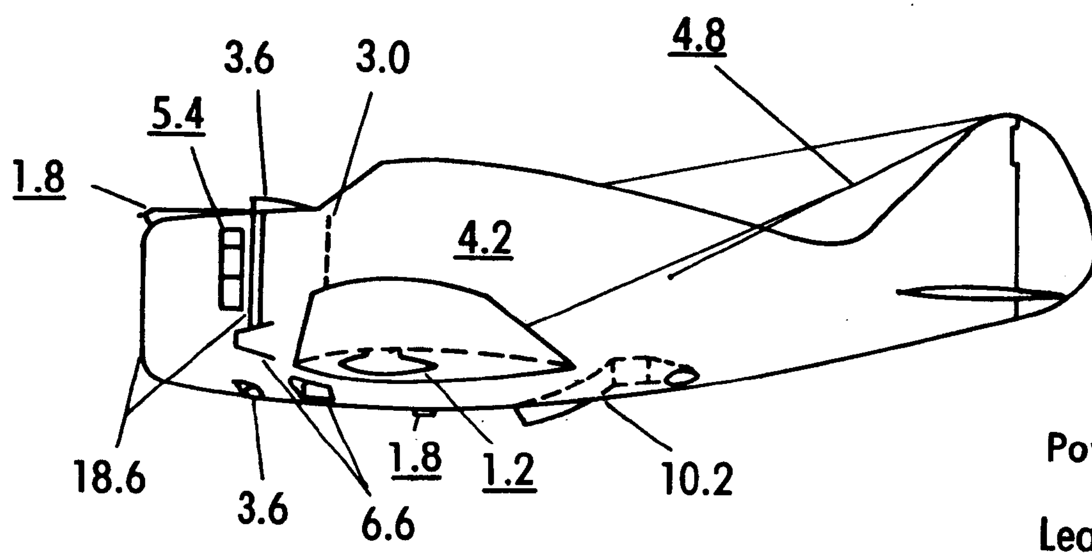


Figure 2. Airplane in the Faired and Sealed Condition



Note: Numbers indicate added drag
in percent sealed-and faired drag.

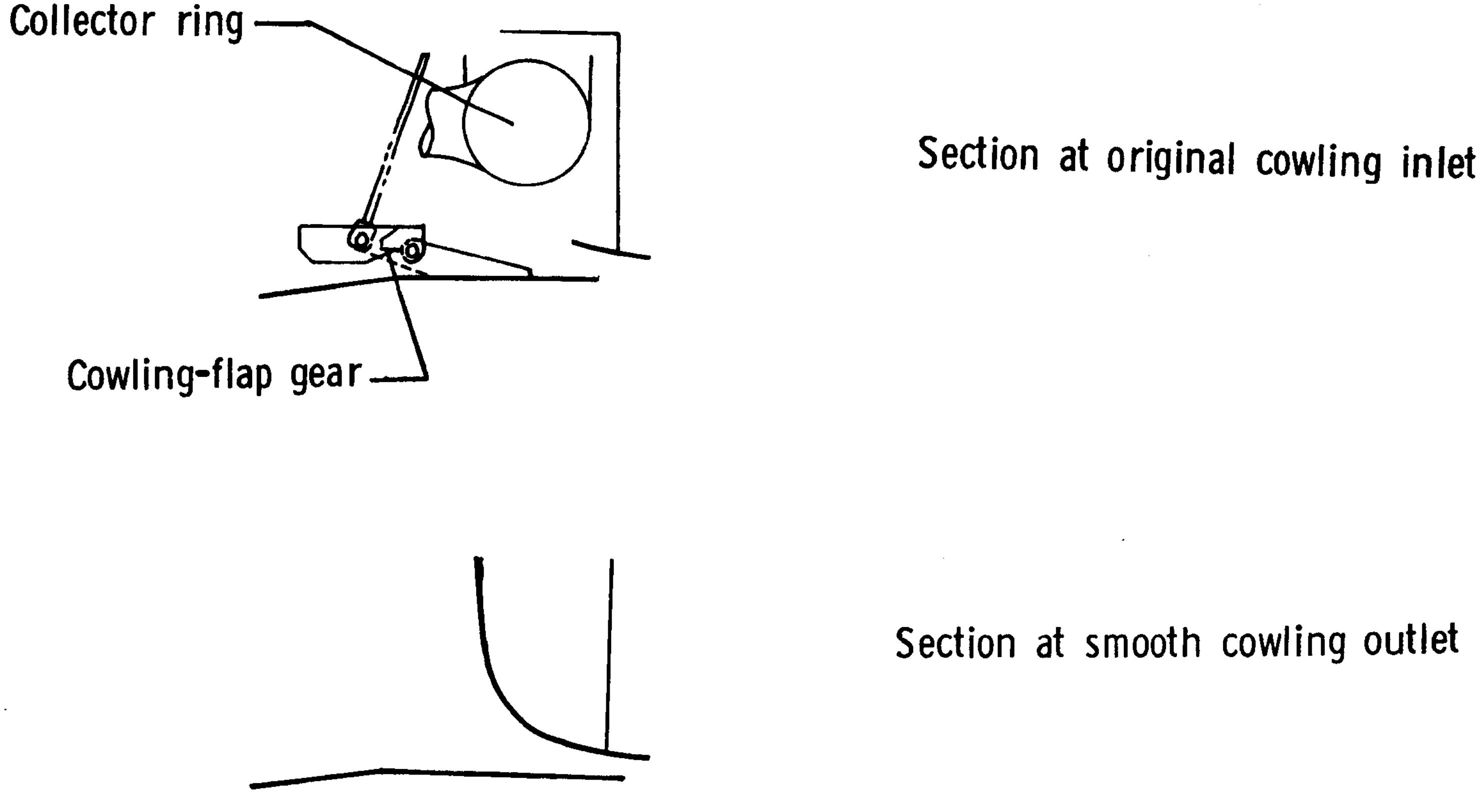
Figure 3. Airplane with Power-Plant-Installation Drag Items Added



Power plant	45.6
Leakage and roughness	19.2
	64.8
Possible reduction	35.7

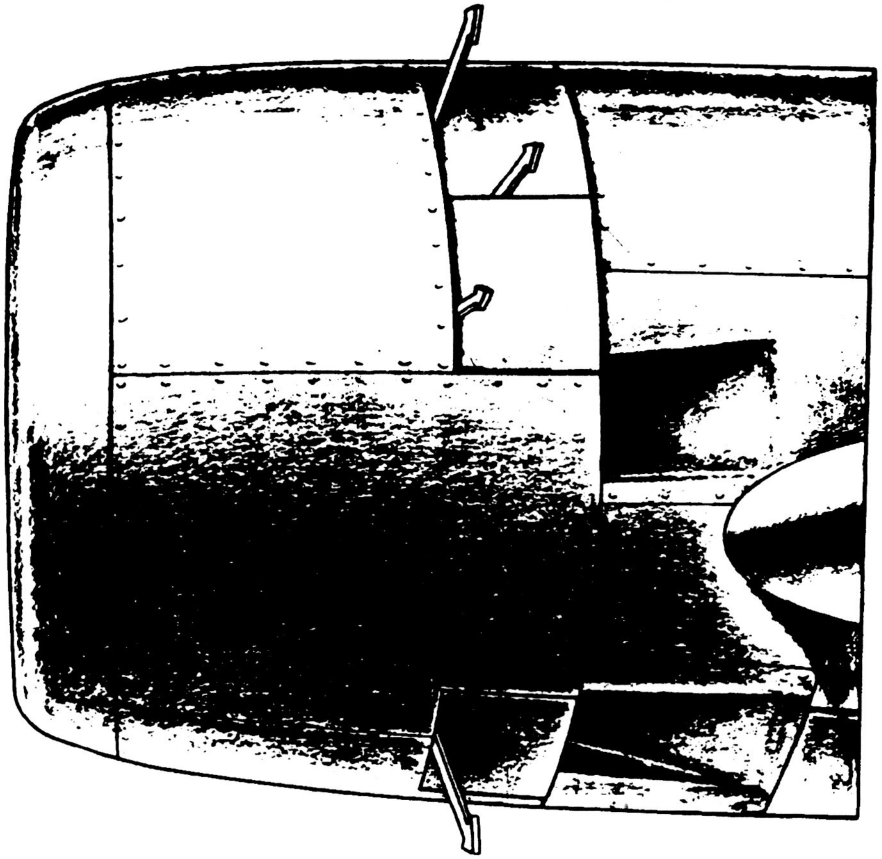
Note: Numbers indicate added drag in percent sealed-and-faired drag.

Figure 4. Airplane in the Service Condition



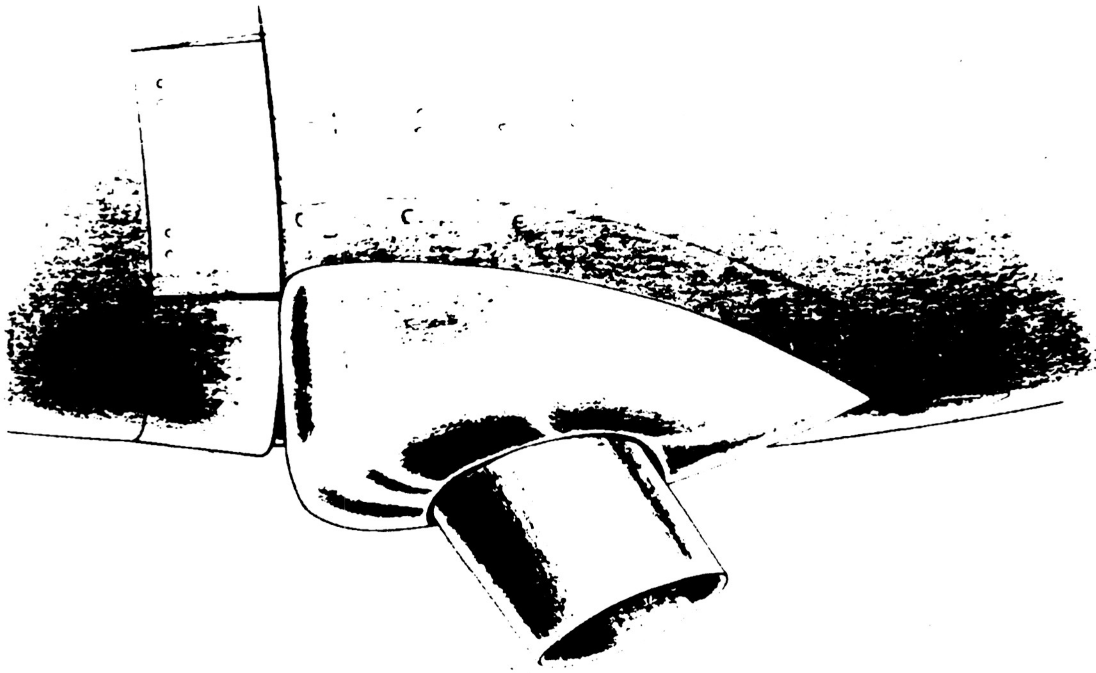
$\Delta C_D = 0.0007$ or $5\% \; C_{D_f}$

Figure 5. Engine-Cowling Outlet



$\Delta C_D = 0.0005$ or $4\% \ C_{D_f}$

Figure 6. Cowling Flap Leakage



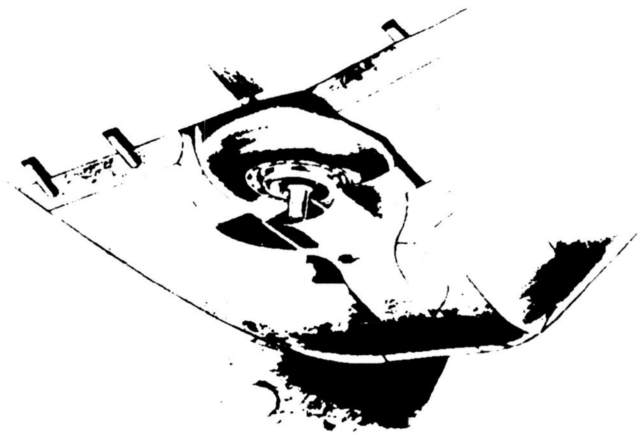
$\Delta C_D = 0.0021$ or 16% C_{D_f}

$\Delta C_D = 0.0010$ or 8% C_{D_f}

Figure 7. Exhaust-Stack Drag

Full length fairing, not sealed

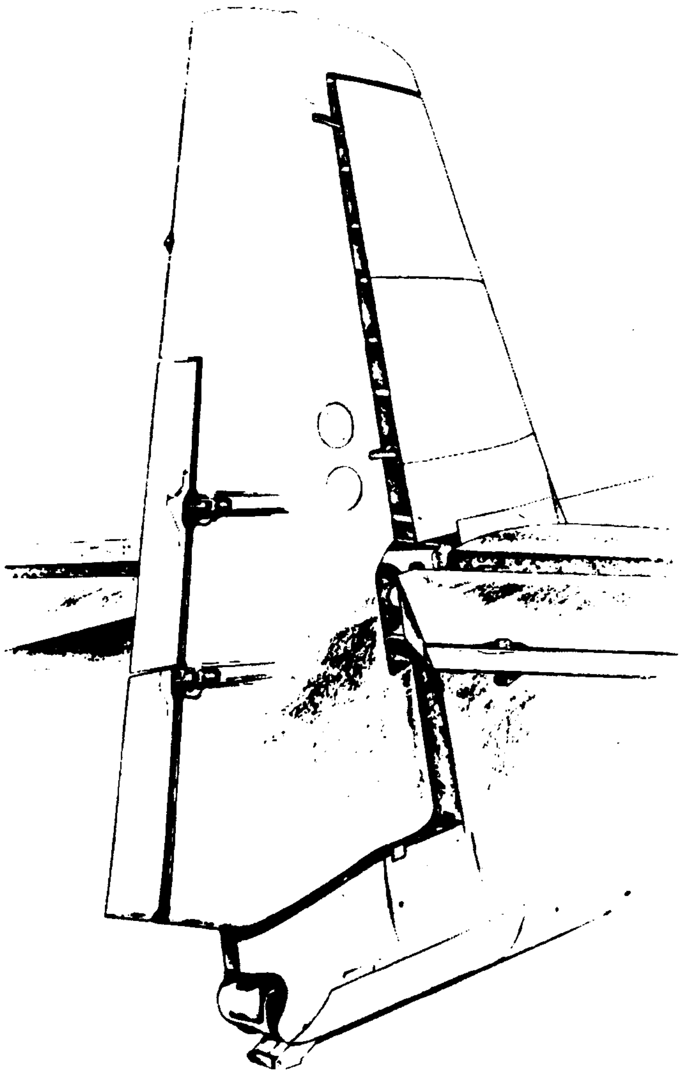
$\Delta C_D = 0.0009$ or 7% C_{D_f}



Short length fairing

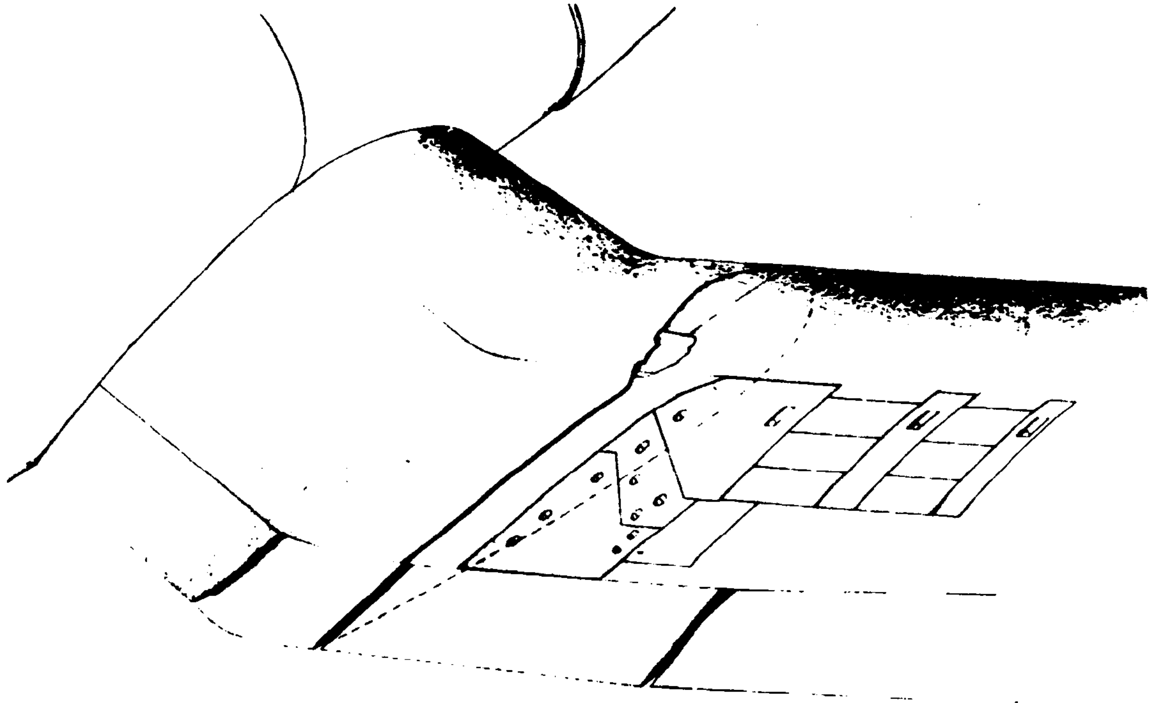
$\Delta C_D = 0.0012$ or 9% C_{D_f}

Figure 8. Landing Gear Drag



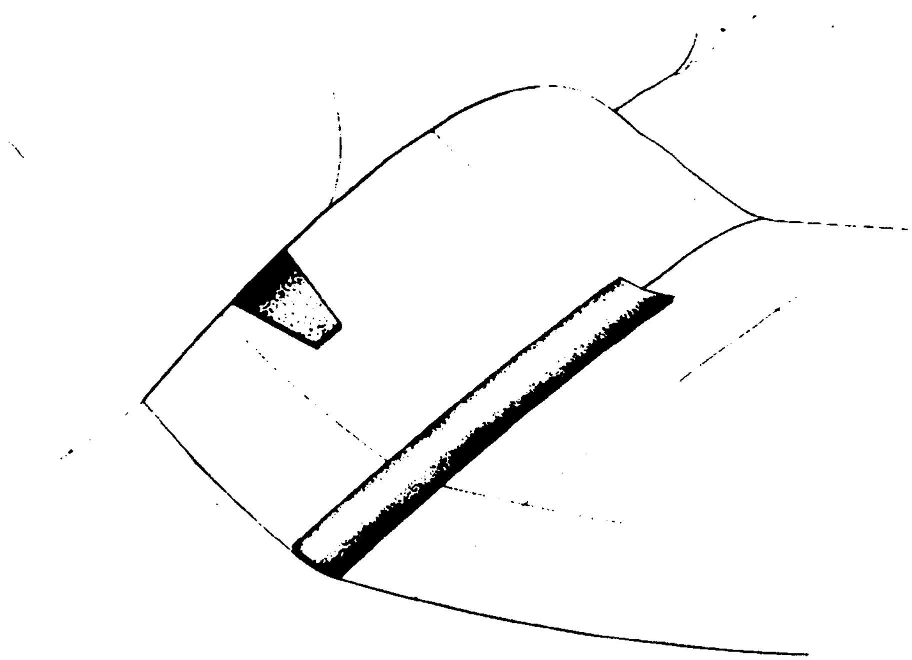
$\Delta C_D = 0.0007$ or $5\% \ C_{D_f}$

Figure 9. Control Gap Drag



$$\Delta C_D = 0.0012 \text{ or } 9\% \ C_{D_f}$$

Figure 10. Irregularities and Leakage



$\Delta C_D = 0.0010$ or 8% C_{D_f}

Figure 11. Sanded Walkway