Where Did The Speed Go?

NACA engineers compiled data on the nature of drag that can help the lightplane designer.

Life is filled with little problems. You designed your Superfire 400 to fly at 400 mph and it only does 300. Glumly, you try to determine exactly where you went wrong in your calculations. Don't be too discouraged. Aircraft designers have been struggling with this problem since they began predicting aircraft performance. Most likely, you did your math right. It's during the conversion from streamlined paper design to a practical, flyable airplane that the slowdown occurred.

Fortunately for you, there was a group of U.S. engineers during WW-II that showed, step-by-step, what occurs when transitioning from a wind tunnel model to a flyable airplane. They recorded their findings, and the results can help you understand how necessary configuration changes will affect the speed of your design.

Thank Uncle Sam

During WW-II, engineers at the National Advisory Committee for Aeronautics (NACA) used the facility's 30x60-foot, full-scale wind tunnel at Langley Field to study drag effects on full-scale fighter plane designs. They were striving to understand how to build faster-than-ever, prop-driven planes. Drag cleanup tests were conducted on more than 20 warplanes. During the tests, NACA engineers made each test subject super clean by taping over every opening, removing any protruding parts and fairing or reshaping any irregular areas that might cause flow separation. Thus, they would test the design in its lowest possible drag condition. Then they would, one step at a time, unseal, unfair, and add back each item until the plane was once again in its original configuration.

Drag was measured at each step, giving the aircraft designers data on areas for improvement of this aircraft as well as future designs. On some designs they found that it would take more than twice the horsepower to push the service-condition aircraft through the air at the same speed as the clean-condition aircraft. If both used the same size engine, the clean configuration would fly more than 25% faster than the factory-delivered configuration.

One of the aircraft studied was the Seversky XP-41. The low-wing, all-metal experimental fighter was powered by a Pratt & Whitney R-1830 engine. The engine was supercharged and provided 1100 hp at a 15,000 foot altitude. The XP-41 never went into production, but if its looks are familiar, that's because it was the grandfather of the P-47 Thunderbolt.

During the NACA tests, a full-scale, cleaned-up XP-41 underwent 18 modifications that increased drag incrementally. NACA engineers meticulously recorded the individual and cumulative effects of each change, and insights gleaned from their research eventually appeared on the P-47 Thunderbolt. Many of the high-drag items on the XP-41 are either absent from or are improved upon on the P-47.

Layers of Drag

Basic geometry parameters such as wingspan, wing area, fuselage shape

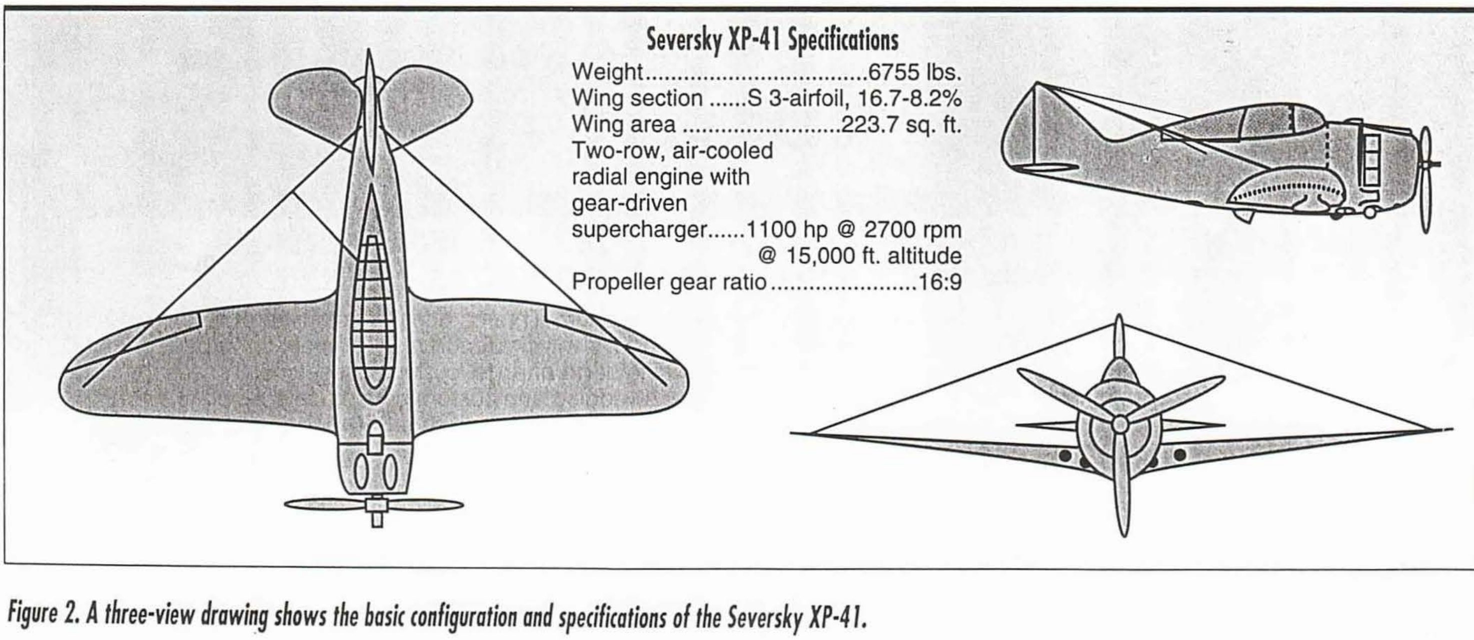


Figure 2. A three-view drawing shows the basic configuration and specifications of the Seversky XP-41.

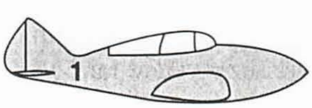
BY MAL HOLCOMB

and fuselage size set the minimum drag that can be achieved by any given airplane design. This minimum drag is due solely to the friction of the air on the airframe. If the shape is wrong, there can be additional drag caused by air separation. For now, let's assume your Superfire is well-shaped and has no separation in high-speed cruise.

So why doesn't it achieve the 400-mph design speed? Well, in reality, the only place this minimum drag can be achieved is in a wind tunnel with a super-smooth model. However, it isn't a slick wind-tunnel model that you are flying but an honest-to-goodness airplane with an engine, cockpit, fuel tanks and retractable gear that goes like a bat out of perdition. All of these extras convert your streamlined piece of art into a real flying machine but they also cause a loss in performance.

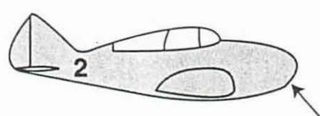
Examining the Evidence

Let's take a detailed look at what each of the 18 items is worth, in terms of speed and horsepower, for the XP-41. This may help you determine how fast your design will fly. Table 1 gives a rundown on the cruise speed that could be obtained with the production engine at 15,000 feet, the horsepower that it would take to reach 400 mph and 15,000 feet, and the incremental horsepower at 400 mph and 15,000 feet for each configuration. The following is a short discussion of each item and how it relates to a typical general aviation airplane:

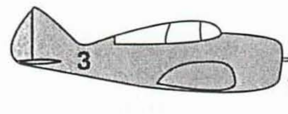


To begin, we have the sealed and faired XP-41 as a baseline. The radial engine nose was lengthened and streamlined to minimize drag. The drag for this configuration comes from skin friction, control surface gaps and mutual interference between the wing, fuselage, empennage and windshield. The XP-41 was built with all-metal construction and flush rivets, thus making for a low skin-friction coefficient. To further reduce drag, the control-surface gaps were kept to a minimum and were probably tighter than most general aviation airplanes. Lightplanes typically have 1/4-inch gaps and require 50 hp to overcome the gap drag at 400 mph.

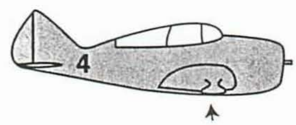
The windshield was well-rounded, resulting in low drag. Interference drag was minimized on the XP-41 by a fillet between the low wing and the round fuselage. There were also fillets at the junction of the rail surfaces and the fuselage.



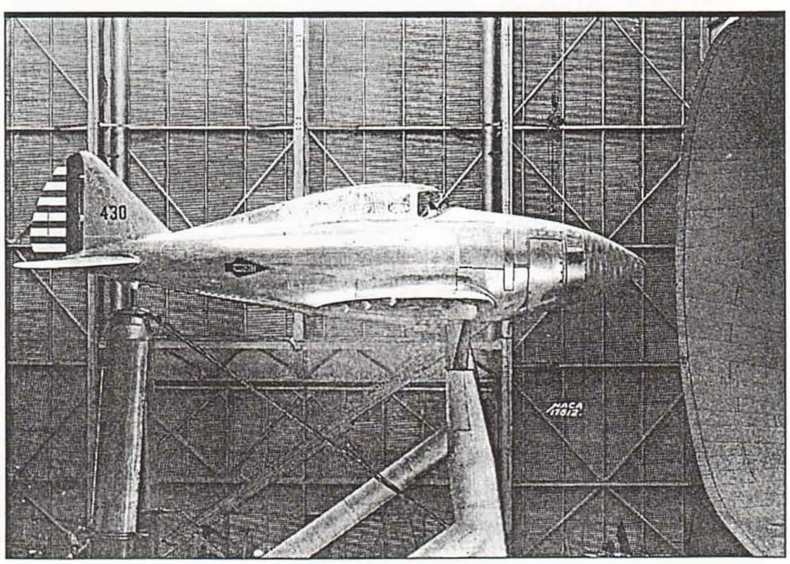
The second configuration change was a slight blunting of the lengthened nose fairing. This resulted in a slight increase in drag, reducing speed from 382 knots to 380 knots at 15,000 feet.



The streamlined nose fairing was removed, leaving the production cowling with its radial engine. Remember, at this stage, the exits were still sealed, so there was no drag due to airflow through the cowl. The drag difference was due to the bluntness of the cowling. General aviation airplanes with horizontally opposed engines have nose shapes between that of configurations 2 and 3. The obvious lesson is that a blunt nose causes drag.

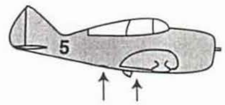


The fourth change was the removal of the sealing tape on the landing gear doors. The XP-41 had a completely retracted landing gear with full door covers. The only drag was from air leakage through the gaps around the doors. The only production, single-engine, general aviation aircraft with

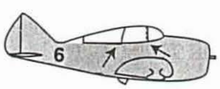


The Seversky XP-41 was designed to be a fighter plane during WW-II. This full-scale, super-clean test airplane was studied by NACA engineers in a 30x60-foot wind tunnel to determine the drag effects of 18 separate modifications.

landing gear as clean as this is the Beech Bonanza. More typical of general aviation aircraft is a main landing gear with no doors over the wheels and even maingear that is partially exposed to the slipstream. At 400 mph, a well-designed, partially exposed landing gear would require 135 additional horsepower to maintain the same speed, based on the XP-39 data.



All piston and turbine engines require oil to lubricate the internal moving parts. Lubricating a hot engine heats the oil, and to cool this oil it takes an oil cooler, which is essentially an oil-filled radiator. The XP-41 has its oil cooler inside the fuselage with an external scoop on the belly to capture cool air and an exit hole farther aft. Step 5 was to install the inlet scoop and unseal the inlet and exit, permitting air to flow through the oil cooler. This design was found to have a significant amount of drag, and it did not cool the oil sufficiently. NACA engineers designed an underslung oil cooler that not only cooled the oil, but did it with approximately half the drag of the original design (68 hp instead of 129 hp at 400 mph).



An obvious requirement for any aircraft is a reasonable way for the pilot to enter the cockpit. In the case of the XP-41, when the fairings over the canopy frame and slide track were removed, the drag went up–the fairings produced more drag than what they were supposed to fair! Most lightplanes have doors, and to minimize their drag, they must be well sealed to prevent air leakage. Care must also be taken to prevent leakage and drag when designing hinges and external handles.

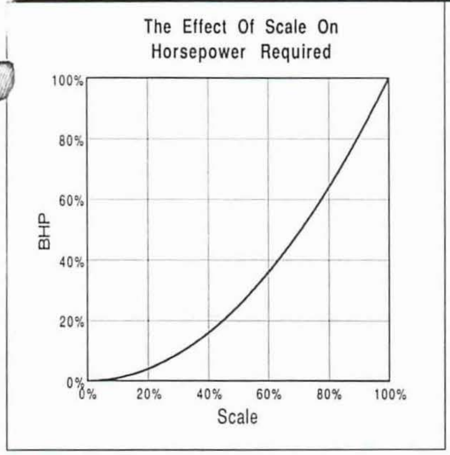
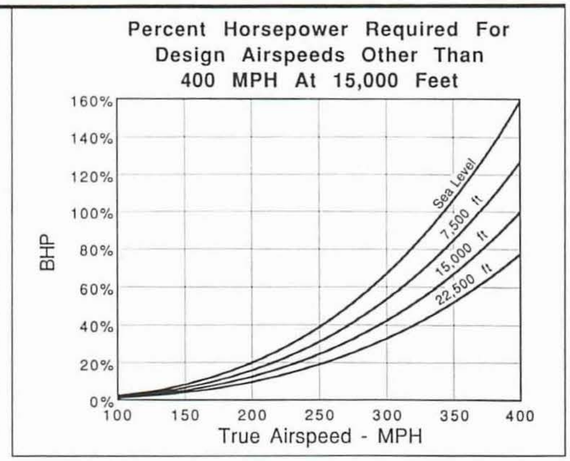
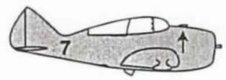


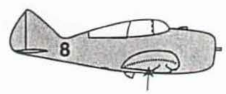
Figure 3 shows the effect of aircraft scale on horsepower.

Figure 4 shows the percentage of horsepower required to fly at different design airspeeds and altitudes.

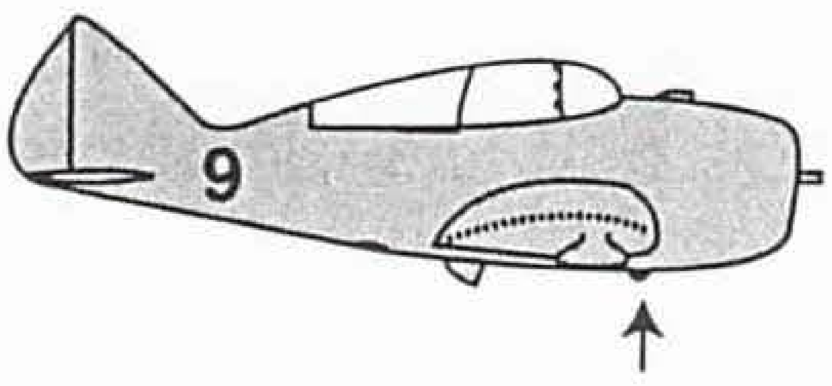




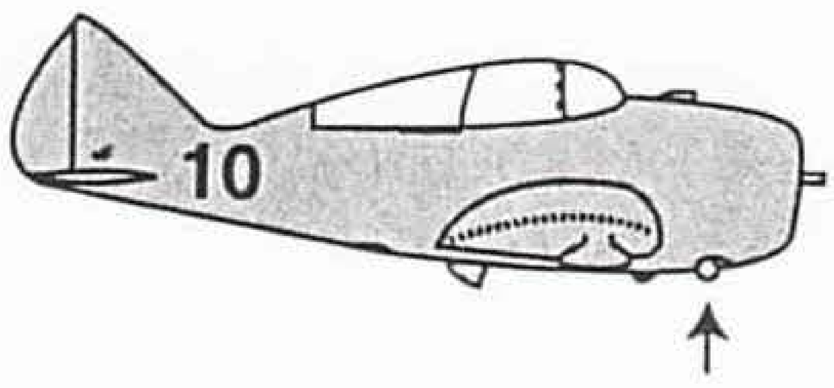
Gasoline engines require air to mix with the fuel to allow combustion. Step 7 of the test was to add a carburetor air scoop. The scoop on the XP-41 did an excellent job providing air to the carburetor, but the NACA engineers suggested that its drag could be reduced by increasing the leading-edge radius of the scoop and lengthening the afterbody. This would have reduced airflow separation behind the scoop.



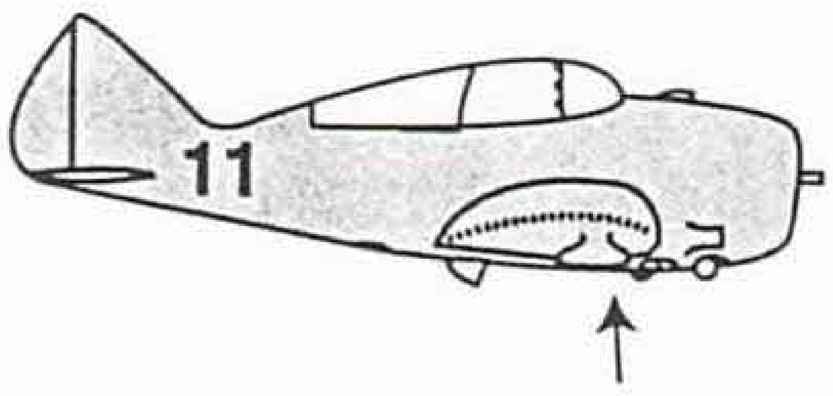
On most low-wing airplanes, the top of the wing is used as a walkway to enter the cabin. The smooth curved surface of an all-metal wing is difficult to stand on, especially if it is wet. To provide a slip-proof surface, a banded walkway is added to the top of the wing. It costs drag, but if people easily slipped off the wing and were injured, what would be the effect on the popularity of the design? The banded walkway is a necessity.



Step 9 was the addition of the ejector chute for the used machine-gun shell casings. The FAA doesn't permit you to drop objects from aircraft when over populated areas, so even if you have machine guns, you better not eject the shell casings.

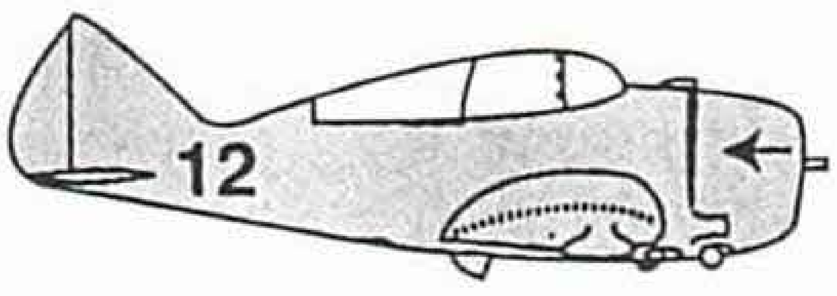


The exhaust stacks were added for the tenth test. There were two stacks and each was approximately 4 inches in diameter with a streamlined fairing in front of each stack. The drag of the exhaust stacks on the XP-41 was ⅓ to ½ the value of most contemporary radial-engine aircraft, and this was primarily due to those streamlined fairings.

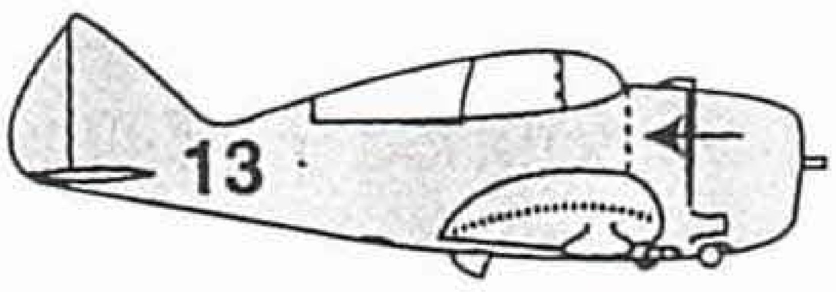


Configuration change 11 was the addition of the intercooler. When a turbocharger or supercharger is used to boost the engine manifold pressure, it also heats up the air. Increasing inlet air temperature causes a loss of power output, which reduces the power increase due to higher manifold pressure. An intercooler is simply an air-to-air heat exchanger used to cool the supercharged (pressurized) air. The XP-41 intercooler had a scoop on the right side of the fuselage, just in front of the wing, to capture the cooling air. The cooling air was exhausted through an outlet on the lower fuselage.

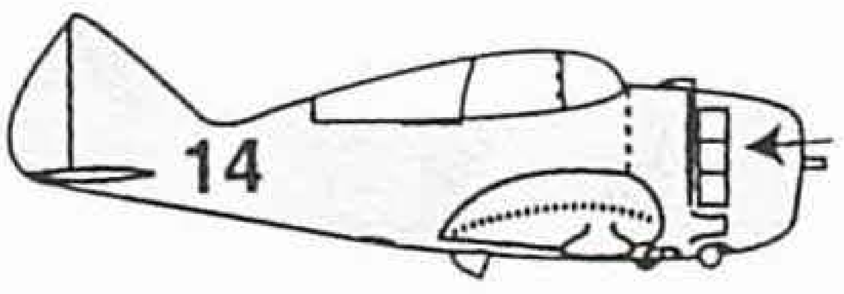
Both the inlet and outlets were well designed and contributed little to the drag of the installation. The majority of intercooler drag came from inefficient ducts in the cooling and engine passages. The intercooler on XP-41 was an add-on installation, and the existing space available in the airframe did not permit an efficient design. Most general aviation intercooler installations are also add-ons and suffer from similar space limitations. Luckily for U.S. pilots, the engineers at Republic Aviation (formerly Seversky) learned form the XP-41 and designed a more-efficient intercooler installation for the follow-on P-47 Thunderbolt.



Step 12 saw the tape over the cowl flap exit removed, allowing cooling air to flow over the engine. The cowl flaps were in the closed or high-speed cruise position. Drag for the cowl flaps in the fully open or takeoff/climb position would be much higher.



The engine is not the only thing that needs cooling. Accessories such as generators and radios also generate heat and need to be cooled. The tape seal over the accessory cooling air exit was removed in this configuration change. On the XP-41, the accessory air was drawn off the engine-cooling airflow and was exhausted through slots on the side of the fuselage at right angles to the external airstream. Today's light planes have far more avionics and accessories than WW-II military aircraft, and particular attention needs to be paid to their cooling.



In Step 14, the seals were removed from all skin joints and cowl-flap hinges. When the air leaks out of these openings, it causes the airflow in that region of the fuselage surface to separate, resulting in higher drag.

DRAG

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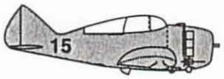
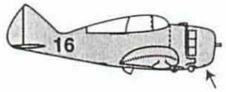
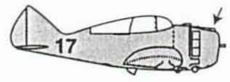


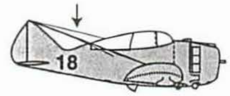
Pilots need aircraft designers to provide them with adequate ventilation systems. Payment for this comfort was a 1-mph decrease in airspeed at 15,000 feet.



Within the cowling of the XP-41 was a venturi to provide vacuum for some of the instruments and systems. The venturi's exit was in the lower cowl. When the seal over the exit was removed, the drag of the air through the venturi could be determined. If an external venturi had been used instead, the drag would have been greater.



This configuration change was the addition of two 0.50-caliber machine guns and their blast tubes to the upper nose cowling.



The final step was the addition of the HF radio antenna. Although most lightplanes do not have an antenna that produces as much drag as the WW-II fighter HF antennas, they do carry far more avionics, including many lower drag antennas of various types. The final result is that the typical general aviation airplane has a total antenna drag about the same as the XP-41.

What Does It All Mean?

The cumulative effect of these 18 incremental changes is that the XP-41, in a realistic configuration, is 15% slower than the initial minimum-drag estimate. In other words, to fly the same airspeed as it could in the low-drag configuration, the real plane would require an engine 66% more powerful!

But how does this XP-41 aerodynamic testing relate to light aircraft design? Typical four-place production light airplanes are about 90% the size of the XP-41, while typical two-place homebuilts are about 70% of its size. Figure 3 shows the effect of aircraft scale on horsepower. From this data you can determine relative horsepower for your size aircraft.

If you desire performance information for other altitudes and airspeeds, Figure 4 gives good results. It shows the percentage of horsepower required to fly at different design airspeeds and altitudes as compared to that for 400 mph at 15,000 feet. The factors from Figures 3 and 4 can be multiplied to obtain the horsepower required at a different airspeed, altitude and scale. These factors can be applied to either the total horsepower or to the change (delta) in horsepower for a particular component.

So, if you're wondering why your Superfire does 300 mph instead of 400 mph, don't be discouraged. Remember that you've designed a real-world, flyable airfcraft and not just a supersmooth display piece. ❑

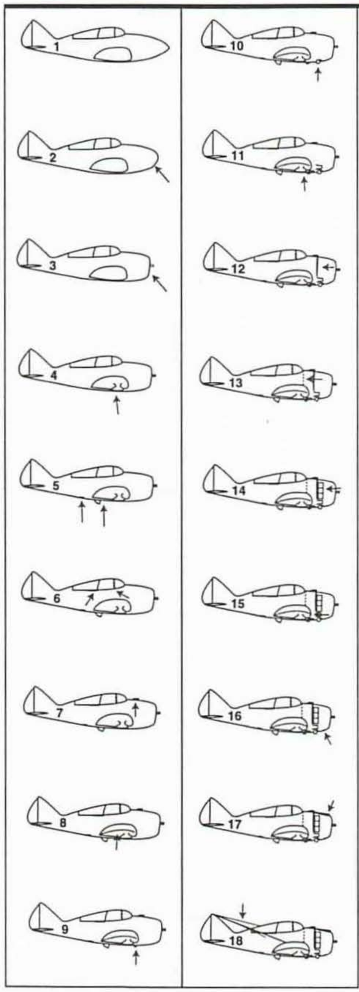


Figure 1. To get from a fully faired and sealed mockup to a configured-for-flight aircraft, 18 incremental changes were necessary.

Condition Number	Description	Cruise Speed with 1100 hp @ 15,000 ft	Horsepower for 400 mph @ 15,000 ft	Incremental horsepower (400/15,000)
1	Completely faired condition, long nose fairing	382	1260	—
2	Completely faired condition, blunt nose fairing	380	1282	22
3	Original cowling added, no airflow through cowling	368	1411	129
4	Landing-gear seals and fairing removed	367	1427	16
5	Oil cooler installed	356	1556	129
6	Canopy fairing removed	357	1540	-16
7	Carburetor air scoop added	354	1586	46
8	Sanded walkway added	350	1639	53
9	Ejector chute added	348	1662	23
10	Exhaust stacks added	345	1707	45
11	Intercooler added	340	1791	84
12	Cowling exit opened	335	1874	83
13	Accessory exit opened	333	1912	38
14	Cowling fairing and seals removed	329	1981	69
15	Cockpit ventilator opened	328	1988	7
16	Cowling venturi installed	327	2003	15
17	Blast tubes added	326	2026	23
18	Antenna installed	323	2087	61
			Total	827

Table 1. Each of the 18 changes are listed, and the effects on required cruise speed and horsepower are tabulated.

References: Paul L. Coe, "Review of Drag Cleanup Tests in Langley Full-Scale Tunnel (From 1939 to 1945) Applicable to Current General aviation Airplanes," NASA TN D-8206, June 1976. James R. Hansen, "Engineer in Charge," NASA SP-4305, 1987