

# HANGAR ECHOES

EXPERIMENTAL AIRCRAFT ASSOCIATION  
CHAPTER 168 DALLAS TEXAS

## Finding Hidden Drag

by K. Truemper

*Editors Note: Thanks to Klaus for providing this article. We are sure you will find this topic very interesting since the performance improvements due to drag reduction to Klaus's Zenith 601 HDS have been absolutely phenomenal.*

For us low and slow fliers, it is convenient to consider the total drag of an airplane to be composed of parasite drag and induced drag. Parasite drag is the resistance produced by irregular surfaces. The airflow is disrupted by such surfaces and becomes turbulent. Bending of smooth airflows creates induced drag. It is easy to see the causes of parasite drag. For example, unfaired gear legs and external antennas are indicators. Induced drag is harder to identify. A sleek-looking airplane may have lots of induced drag and thus may not fly fast. This is a story about such hidden drag.

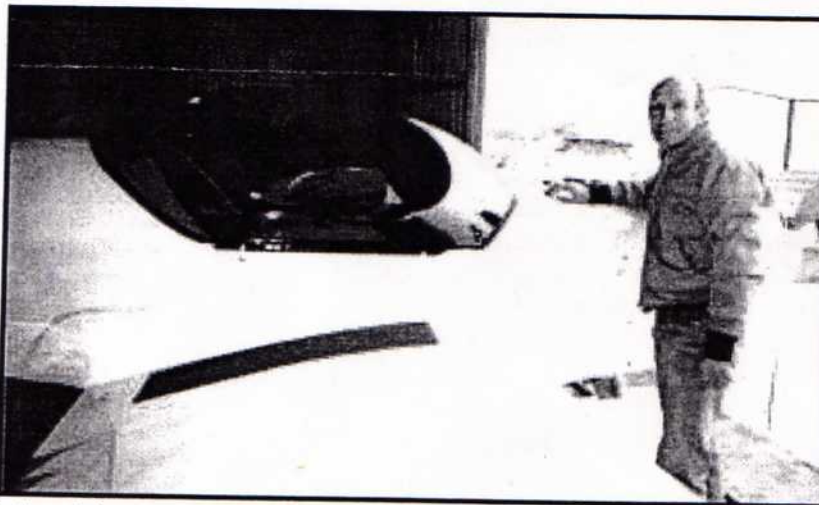
After Mel Asberry and I finished the Zenith 601HDS (N314LB) about four years ago, I made a number of modifications, such as moving the radiator into the cowl, to reduce parasite drag. The changes improved climb and cruise performance. Nevertheless, the plane still had some undesirable flight characteristics that I could not explain and hence could not work on.

(1) In cruise, the plane sometimes would fly fast in level flight. But when a slight turbulence or downdraft would force me to raise the nose just a bit, the speed

would almost instantly deteriorate and then stay at that lower value.

(2) When trimmed for power-off glide, the speed would fluctuate considerably when very small elevator adjustments were made. The sink rate was high regardless of glide speed.

(3) When loaded close to max weight, the plane would require a nose-up attitude for level flight that seemed much higher than I expected to be necessary.



Since small changes in airplane attitude, particularly at low speeds, cannot cause large parasite drag changes, parasite drag could not be the culprit. That left me with induced drag. But how could induced drag do this? That question had me baffled for a long time. Then, after I solved the problem, I realized that the answer had been there

all along, in the shape of the RVs. So, don't expect anything new to be reported here. Any aeronautical engineer is well aware of what I am writing about. But, equally true, the simple facts I will describe have been ignored in some of yesterday's designs and are still being ignored in some of today's designs. There are notable exceptions, in particular the RVs. They are so fast and exhibit such nice behavior because attention has been paid to many things, among them the item I describe here.

*Continued on page 7*



## Hidden Drag

*Continued from page 1*

We need a basic understanding of why airplanes fly. D. Anderson and S. Eberhardt have written an excellent article on this in the February 1999 issue of *Sport Aviation*, "How Airplanes Fly." Another illuminating article is "Foiled by the Coanda Effect" by J. Raskin in the September/October 1994 issue of *Quantum*. Briefly, a flowing liquid or gas tends to follow a smooth surface. You can convince yourself of this as follows. Hold a spoon rather loosely as shown in Figure 1 so that the water running from a faucet flows around the bowl of the spoon.

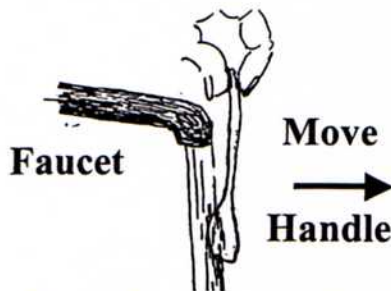


Figure 1. Demonstration of Coanda Effect

Try to move the spoon away from the flowing water as indicated in Figure 1. As you will see, the spoon bowl wants to stay with the flowing water and separates from it only when a surprisingly large force is applied. In the case of the wing of an airplane, the air moving over the top surface of the wing follows the downward slope. See Figure 2.



Figure 2. Airflow over Wing

The air continues the downward movement once it reaches the trailing edge. In effect, the wing pitches the air past the trailing edge at a downward angle. The action of the downward pitching of air creates as reaction a lifting of the wing. This interpretation is beautiful for understanding why airplanes fly. But it does not help much to see what is wrong when a plane does not fly well. For this, one may look at the air pressure above the wing. The air flowing above the wing is effectively bent downward. There is only one thing that could cause such bending: a low pressure above the wing. That low

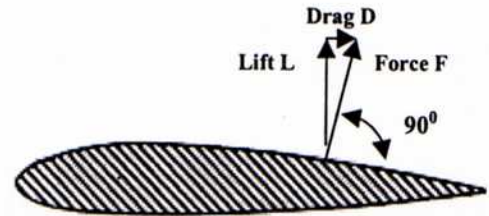


Figure 3. Force F, Lift L, & Induced Drag D

pressure produces a force  $F$  that, when depicted as a vector, rises at a 90 deg angle from the top surface of the wing. See Figure 3

Assuming level flight, gravity is the only force to be counteracted by the lift of the wing. Hence, the required lift  $L$ , which is opposite to and of the same magnitude as the gravitational force acting on the plane, is vertical. If the force  $F$  is to produce the lift  $L$ , it must be somewhat larger than  $L$ , as shown in Figure 3. In fact, the vertical vector  $L$  and the horizontal vector  $D$  must together, in vector addition, give the slanted vector  $F$ . The force  $D$  is the induced drag of the wing. When  $D$  is multiplied by the speed of the plane, and when that product is divided by the propeller efficiency, say 65-70%, one gets the horsepower required to overcome that induced drag.

Thick wings produce more induced drag than thin wings if they create the same lift using the same angle of attack. See Figure 4. Of course, thin wings require a faster airflow than thick wings to achieve that same lift.

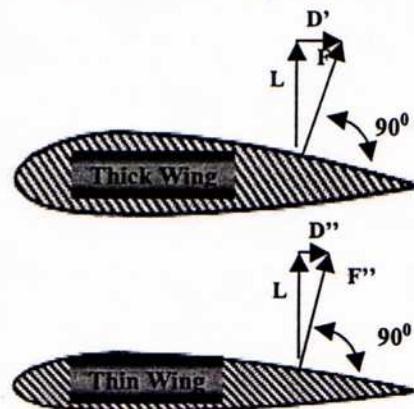


Figure 4. Effect of Wing Shape on Induced Drag

Induced drag is also produced by other parts of the airplane: for example, by the fuselage, by the fairing of the landing gear, and by the tail surfaces. Here we look at just one item, the fuselage.

Suppose a plane looks from above as shown in Figure 5, as does the 601HDS.

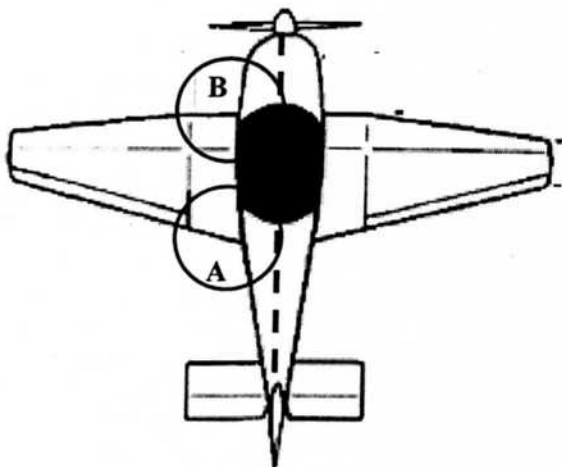


Figure 5. Areas A and B of Fuselage and Wing

Doesn't the fuselage look a bit like the cross-section of two wings put together at the dashed line? This means that the airflow along the fuselage in the area A produces forces F, L, and D shown in Figure 6.

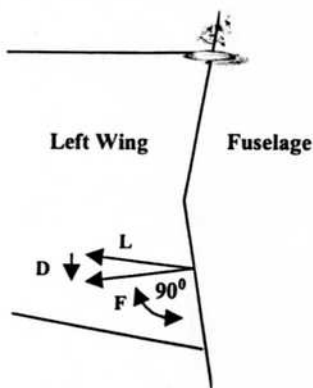


Figure 6. Forces Produced by Fuselage in Area A

The force L tries to pull the fuselage to the left. It is counteracted on the right-hand side of the fuselage by an opposite force of equal magnitude, and thus accomplishes nothing. The force D is induced drag, just as in the wing situation. Near the wing root, both the wing and the fuselage produce low pressure, and thus the induced drag D shown in Figure 6 is larger than if we removed the wing and exposed just the fuselage to the airflow. To get an idea of the magnitude of D in the case of the 601HDS, I made some differential-pressure measurements using Les Palmer's water-column gauge. That instrument is nothing but some clear plastic tubing, a small strip of wood with inch markings, and two plugs that cap the two ends of the tubing except that they have a few very small

holes. See Figure 7. By the way, that instrument is helpful when one wants to determine the location of an oil cooler or water radiator and the related ducting of air, or when one wants to find out why an existing oil cooler or water radiator is not working well. I used it extensively during the redesign of the cooling system for the 601HDS.

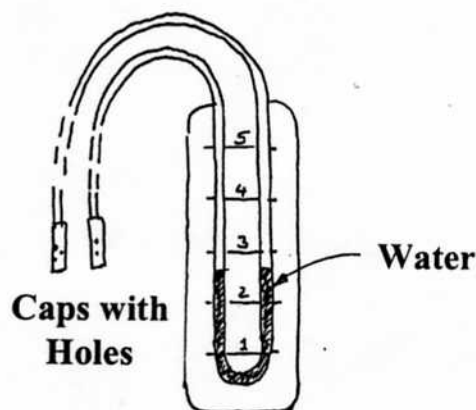


Figure 7. Water-Column Gauge

One probe was inside the cockpit. The other one was placed at various points on the outside sidewall of the fuselage. From these measurements, I estimated the induced drag caused by the bulging-out of the fuselage over the wing during climb and level flight. Using 100 kts as reference speed and a guess of 65% propeller efficiency, I computed that the additional induced drag required about 3 hp in level flight and about 6 hp in climb. This was at a 70% power setting of the Rotax 912 engine, which gives an output of 56 hp. So in cruise, more than 5% of the engine output was wasted due to the

induced drag of the bulging-out fuselage over the wing. In climb, it was more than 10%. These numbers indicate that there is a significant loss of efficiency.

But more needs to be considered. Let us look at the area B of Figure 5, enlarged here in Figure 8.

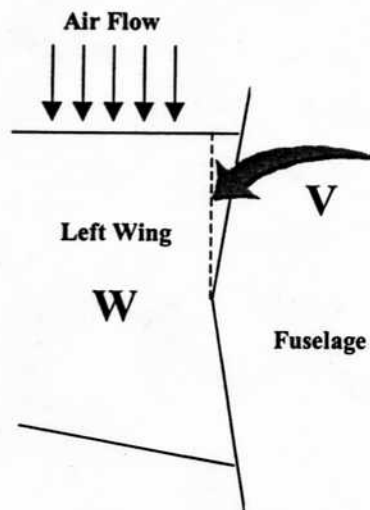


Figure 8. Airflow in Area of B



The top surface of the left wing has been divided by a dashed line into the main area W and a triangular sliver V. Imagine the airflow across the main area W. As we have seen, that airflow is bent by the top surface of the wing and thus creates a low pressure over the wing. What happens to the airflow into the triangular area V? That air has nowhere to go but across the dashed line into W. Thus, the air of V is injected into the low-pressure air over W near the wing root. The result is an increase of the air pressure over W and, therefore, a reduction of the lift produced by W. To compensate for that loss of lift, one must increase the angle of attack of the wing, with corresponding increase of induced drag. Thus, V indirectly increases the induced drag of the wing. A rough estimation using volumes for the case of the 601HDS indicates that the loss of lift and the corresponding increase of induced drag are substantial.

We have seen that a plane with fuselage shaped as in Figure 5 has significant induced drag created directly or indirectly by the bulging-out of the fuselage over the wing. What is the cure? First, one should avoid such bulging-out. Just look at the RVs, where the fuselage sidewall over the wing is straight and at a 90 deg angle to

TOP VIEW (RHS)



tests. There are too many numbers to be included here, so I just listed a sample of the test data. The fuel tanks were filled with approximately 16 gal, which corresponds to 4+ hrs of endurance. By the way, capacity is 22 gal, which gives 6 hrs endurance. Temperature was around 60 deg F, and altitude for the tests was around 2,000-3,000 ft except for the ceiling test. We loaded the plane in three ways.

Case 1: total weight 860 lbs (pilot only).

Case 2: total weight 1,020 lbs (pilot and copilot).

Case 3: total weight 1,080 lbs (pilot, copilot, and 60 lbs baggage).

Power-off stall speed at 1,020 lbs: BEFORE 50 KIAS (kts indicated airspeed), AFTER 42 KIAS.

Power-off best glide at 1,020 lbs: BEFORE 65 KIAS with 1,000+ ft/min sink rate, AFTER 56 KIAS with 650 ft/min sink rate.

Best climb rate at 1,080 lbs: BEFORE 500 ft/min at 65 KIAS, AFTER 800 ft/min at 55 KIAS.

Low-power cruise speed at 1,080 lbs, running the Rotax 912 at 4,700 RPM or 65%, using 3.7 gal/hr: BEFORE 87 KTAS (= kts true airspeed), AFTER 92 KTAS.

Ceiling at 860 lbs: This could not be tested since the plane easily reaches 14,000 ft, the legal limit without oxygen. But we did test the climb rate right at 14,000 ft (15,500 density altitude) and full power: BEFORE 150 ft/min, AFTER 300 ft/min.

Amazing what a bit of fiberglass can do. Are further improvements possible for the 601HDS? Yes. But first we will enjoy summer flying.

RHS VIEW



the wing spar. Second, if a plane does have a fuselage bulging out over the wing, one may want to consider a modification to alleviate the negative effects. In the case of the 601HDS, I made fiberglass fairings that, looking from above, attempt to simulate a straight fuselage. Photos taken by Marvin Brott show the shape of the fairings. Les Palmer worked on the surface finish until it became, well, perfect. Mel Asberry helped to mount the fairings on the plane.

The fairings solve the three problems mentioned at the beginning. (1) Small attitude changes no longer cause sudden deterioration of air speed. (2) Power-off glide is stable and the sink rate is much reduced. (3) The plane no longer requires nose-up attitude in level flight when heavily loaded. There are additional benefits, such as improved climb rate, increased cruise speed, and reduced stall speed.

We ran extensive "BEFORE" (prior to installation of the fairings) and "AFTER" (after installation of fairings)