Klaus Savier's *Determinator*

He makes speed mods look EZ

BY LYNNE WAINFAN, PH.D., EAA LIFETIME 504**

KLAUS SAVIER CALLS HIS Long-EZ the *Determinator*. The airplane's name seems to be a "quadruple entendre": Klaus is determined to terminate inefficiency, and he wanted to use the plane to determine what can be achieved in efficiency and performance. Or, the name could reference Klaus' German accent; he sounds a bit like Arnold Schwarzenegger's movie character the Terminator would, if he had ever been the poster boy for experimental aviation.

Klaus Savier and his Determinator, *a much-modified Long-EZ.*

Klaus, the stocky, serious, self-taught engineer, said, "I've made hundreds of improvements, mostly aimed at going faster." He started experimenting in 1983 with his VariEze. (He calls that the *Delaminator*.) Thirty-one years later, he still continues to improve his airplanes. Some of the VariEze improvements were in the propulsion system—more sophisticated intake tuning and a better fuel-injection system. Aerodynamic modifications were more numerous: changes to the canard elevator slot; upswept canard tips; and a new canard airfoil, among others.

The result of all those improvements? Klaus increased the VariEze's speed from 183 to an amazing 260 mph. His experimentation made him go—can you believe this—42 percent faster! Also, if he flies at 15 percent power, the VariEze can get 100 mpg.

Klaus considered buying a partially completed Long-EZ back in 1985, but he wasn't very optimistic about its performance over his modified VariEze. "At first glance, there was no chance that the Long-EZ could do any better," Klaus explained. "It could only burn more fuel." He ended up buying the Long-EZ at 10 cents on the dollar but continued to work on the VariEze for several more years. Eventually Klaus had so many parts left over from his VariEze modifications that he figured he should just incorporate them onto his Long-EZ project.

So what did Klaus do to his airplanes to make them go faster? Lots and lots of little things.

Before we get into specifics, some words of caution. "Do not try this at home," he warned. "Changing little things on an airplane, especially a canard, can have big effects, mostly negative." *EAA Sport Aviation* (November 2009) reported that bugs, paint stripes, or even rain near the leading edge of a canard can increase minimum flying speed and cause pitch changes.

Klaus' cautious approach is how he has developed an impressively methodical and exceptionally thorough process to make his planes go faster. For each improvement he contemplates, he goes through four phases:

1. Understand the situation.
2. Design a fix.
3. Test the fix.
4. Repeat until satisfied. (This would be "never satisfied" for Klaus.)

The improvements Klaus has made fall into three categories. The first is with the propulsion system: intake, ignition, exhaust, propeller, and fuel subsystems. The goal here is to improve efficiency and run the engine at lower rpm.

Photography by Lynne Wainfan

The second category includes aerodynamic improvements: reducing drag and improving flying qualities.

Then there is the eternal desire to reduce weight at every feasible opportunity.

Let's take a look at some of Klaus' modifications.

PROPULSION SYSTEM IMPROVEMENTS

Klaus' plans to improve his Long-EZ were thwarted a bit in the beginning when his engine wouldn't run right. "It acted like a fuel-injection issue, like excess fuel would get injected and cause a rich miss," he said. "It was hard to find and hard to fix. I struggled with it for almost two years."

The methodical Klaus admitted that he had been looking in the wrong place—fuel injection. Instead, it turned out to be poor intake design. He had finally accomplished step one of his four-step process: He had understood the situation.

Now that Klaus found the general source of the problem, he had to return to step one: Find out what exactly was happening inside the intake. Klaus outfitted the Long-EZ's intake with a pressure sensor for a portable oscilloscope and went flying.

But Klaus had to get good measurements. He advises that magnetos make it very difficult to understand what's going on with other parts of the engine. Klaus said, "Their weak and short-duration spark delivered at greatly fluctuating degrees causes so much scatter in exhaust and intake pressure waves as well as Lambda (mixture) values that they mask other problems."

A precisely timed, powerful electronic ignition removes a lot of variables in the pressure data and shows other issues such as fuel atomization more clearly.

Klaus is a recognized expert and advocate of electronic ignition for light airplanes. He is appalled that after three decades of automotive use, aircraft engines don't use electronic ignition as standard equipment. In addition to helping with clear measurements of what's going on in the engine, "electronic ignition provides an immediate 10 percent reduction in fuel consumption with 5 to 10 percent increase in power," he said. He uses Plasma III systems that are triggered directly at the crankshaft, reporting that "these systems have around 0.5 degree of timing accuracy and can be varied by 1/10 of a degree. Their spark energy is about three times that of any mag."

Klaus applied another automobile technology to improve his Long-EZ engine—a tuned intake. How do they work? Ambient air gathers speed as it rushes into the intake pipe during the intake stroke. At the end of the intake cycle when the inlet valve is closed, the high-velocity air hits the valve and compresses. This high-pressure air can't go into the engine, so it bounces back through the intake pipe. Then it hits the plenum on the other side and bounces back toward the engine. This pressure wave travels back and forth until the valve opens again. Figure 2 shows one of Klaus' oscilloscope readings for this pressure wave. Note that the big dip is the piston sucking.

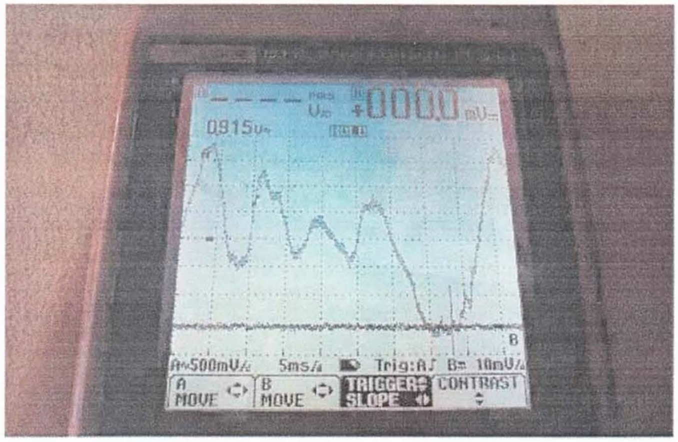


Figure 2: An example of an oscilliscope reading showing the effect of Klaus' tuned intake.

If the high-pressure wave happens to hit the valve at the exact moment that the valve is opening, then it acts like a supercharger!

In order to accomplish this feat, we need to tune the frequency of the pressure wave so that it hits the valve as it is opening. In cars, this frequency is affected by engine speed and manifold length. You pick an engine speed where you want the effect to peak, and then change the manifold length appropriately. A longer intake manifold gives the best tuning performance at low speeds; a shorter intake manifold gives the best effect at higher rpm.

Tuned intakes have been on cars and motorcycles for a long time, but they are relatively recent additions to light aircraft engines. Aircraft engine intakes are somewhat easier to tune than cars or motorcycles because their rpm range is smaller. On the other hand, the tuned intake must fit inside an aircraft cowling and works best over a limited altitude. The main variables that are considered in tuning an aircraft engine intake are altitude plus the length and the diameter of the intake tube.

Because car and motorcycle intakes do not have to be efficient at widely varying altitudes, the traditional way of designing a tuned system is to use a dynamometer—a workbench instrument that measures an engine's torque. Klaus explained, "When done on a dyno, you have to make different intake manifolds, which is a huge pain to do. But [air] density changes the resonance. So you can use the airplane as a dyno and fly to different densities and watch the resonances change." This is the best method to design a tuned intake because doing it on a dyno would take years building different tubes for different altitudes; and altitude is almost impossible to simulate on a dyno.

Klaus reported that understanding, fixing, and testing his tuned intake took two years.

Once the intake was tuned, Klaus turned next to the exhaust on the *Determinator*. Tuned exhausts have been used on a variety of engines: automobile, motorcycle, aircraft, and even model aircraft. An untuned exhaust sometimes has the problem that the exhaust gas from one cylinder can travel out and then *up* the exhaust manifold to a second cylinder's exhaust. When that second cylinder's exhaust valves open, its exhaust gas is met with high pressure from the original cylinder's exhaust. This means that the second cylinder's exhaust gas doesn't completely leave the cylinder. A tuned exhaust, on the other hand, reduces the exhaust pressure right before the port closes, using resonances like those occurring in the intake system. This lets spent gas out of the cylinder and fresh mixture into it, improving engine efficiency.

"I talked to all sorts of people who were knowledgeable about exhaust systems," Klaus said. "One let me use his shop. I spent six weekends and $2,000 worth of material. After all these modifications, the best I could do was 10 pounds *more* weight and 6 knots *less* speed. This was one of my bigger mistakes." Klaus urges caution when talking to experts, as it's easy to get bad advice. Because of that experience and because there is so little room for a longer exhaust on a pusher airplane, the Long-EZ's exhaust is still on his list of future improvements.

Next, Klaus decided on a timed-sequential, fuel-injection system. Traditional injectors fire all or two injectors as a group, regardless of whether the cylinder is ready or not. A timed-sequential system opens the injector during a specified period in the intake cycle. Because of cowling constraints, Klaus had to buy a smaller injector so he could put it in a better location.

A different kind of problem came when Klaus put a header tank behind the cockpit to replace the traditional external sump blisters. He installed a transfer pump to fill the header from the left main tank. A standpipe prevents accidental overfilling of the header tank. In flight, when the air hit the common vent, the dynamic pressure actually pushed fuel *into* the header tank, keeping it full. The solution? Reduce the area of the vent opening. Klaus made a new vent by wrapping carbon around the cap of a felt marker. Figure 3 shows Klaus' header tank—with visual fuel gauge—and carbon vent tube.

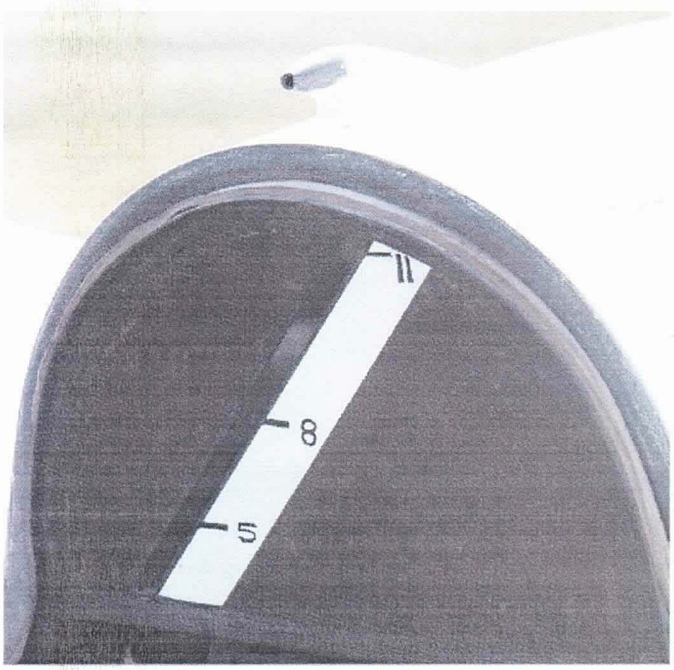


Figure 3: The header tank with a visual gauge.

What about the propeller—was there anything to be gained from modifications there? Klaus, through his company Light Speed Engineering, has designed, built, and tested more than 50 propellers for different aircraft. He knows how to optimize their shape.

"It's really hard to get speed out of a propeller," he said. "It's tough to increase the propeller efficiency of a good propeller. All you can do is increase the maximum rpm where the engine makes more hp." Propeller modifications let you set your optimal performance at lower rpm, saving wear and tear on the engine and reducing fuel costs. But again, he has made discoveries that go against the conventional wisdom. For the *Determinator*, he uses a carbon, fixed-pitch propeller that he designed and hand carved to an amazing 100-plus inches of pitch. It turns at 2,600 rpm.

Making real propeller improvements aerodynamically is also structurally challenging. Klaus cautions that metal props don't work on pusher airplanes. "The blades get excited by the wake of the wing and cowling, and the aluminum, with its characteristically poor fatigue life, will fail sooner or later," he warned. "All of the wood and most of the composite props are fairly thick in order to have adequate structure. Aerodynamic improvements come mainly from using a much thinner airfoil. But these thin blades are difficult to shape and require a vacuum-bagged laminate of very high strength. Thin airfoils are also very sensitive to angle of attack. This means that if the pitch distribution does not correspond to the inflow angles, the blade will stall." Klaus said that a racing propeller is also on his list of future changes.

Klaus has an unusual take on prop mounting. "In the 1930s, we stopped using wood propellers due to the increase in horsepower and the better performance of metal props," he said. "We went from eight [mounting] bolts used for wood props to six bolts, which are plenty for a metal hub." Wood is less stiff than metal, so the bolts see more bending load. On the Long-EZ project, he actually broke bolts at two different occasions before having a set of custom bolts made. "Very expensive," he said. For his 250-hp engine, he hopes that the industry standard for wood props lowers the bolt ending load, returning to eight bolts instead of six, and a crush plate that is splined to the shaft.

AERODYNAMIC IMPROVEMENTS

Klaus has made dozens of changes to the way air flows over his airplane. Recall that the first of our four-step process is to understand the situation. How does Klaus understand the air?

Readers of last month's *Experimenter* will recall from my article that we aeronautical engineers are obsessive about visualizing airflow. We look for it in smoke trails, coffee cream, Saturn's swirls, and movie stars' cigarette smoke. Klaus is widely recognized as the world's flow visualization guru. He uses whatever method he can find, but the main techniques are oil flow and impingement.

In the oil flow method, special dark-colored oil is put on the airplane before flight. After landing, the oil tracks show where the air was—or was not. Klaus has a finely tuned mixture for his oil: He starts with carbon black, the fine black powder that is added to paint base to make it black. Carbon black is available on the

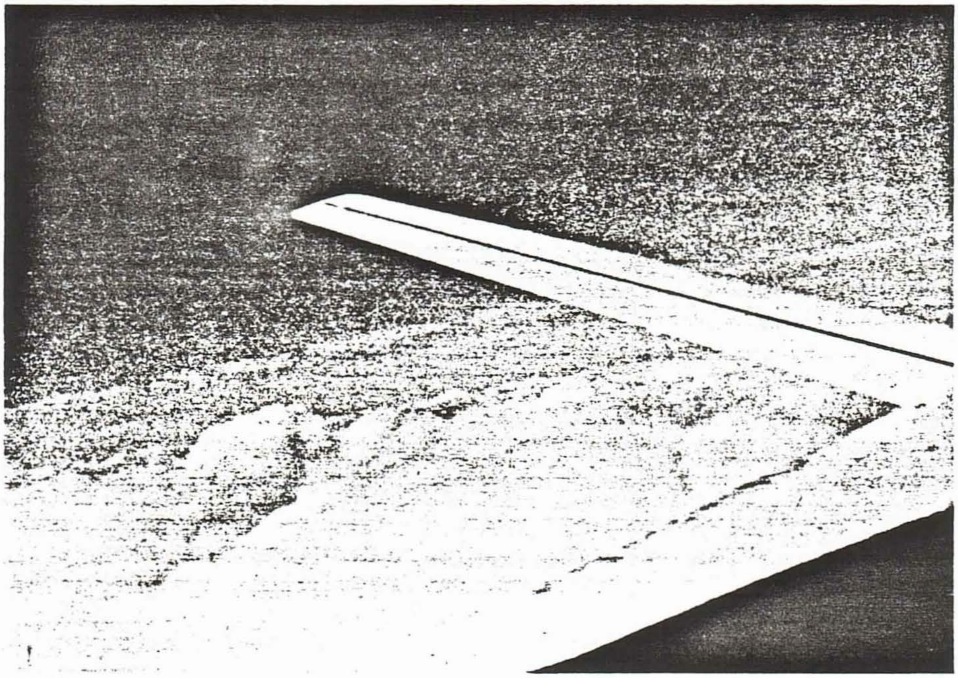
Photography by Lynne Wainfan

weight at take off, and used only 64 gallons of gas and one quart of oil. I did a lot of joy riding of friends, so it was not all at cruise, but when moving between cities I cruised between 8500 and 11,500 feet at about 65 percent power. Even with that great economy Jeanette and I made the trip from Kansas City to Houston in a little over four hours. With the breather set-up we have I don't get any oil blown out even at max climb.

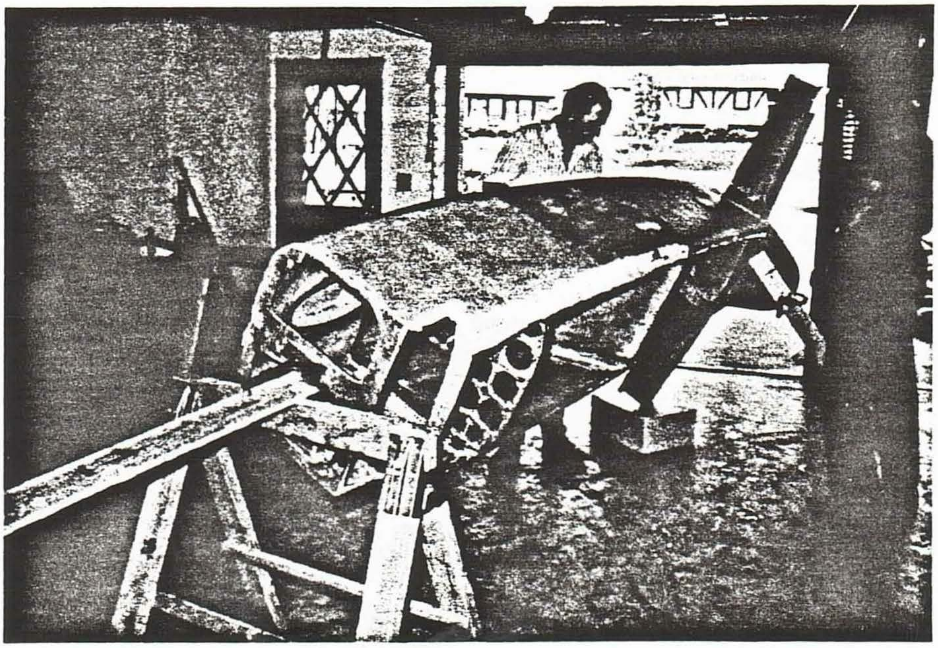
Jim Ball made some very interesting modifications in the engine installation and a set of short exhaust pipes that have given no trouble. I hope he will submit a write-up about what he has done on 25JW, for some of you may be interested.

My sincere thanks to those mentioned, and to Wally Kinate and Gerry West (who along with Jim Ball are members of the church I serve as Senior Minister), and to John Mitchell, Larry Denning, Jamie Miadment, people at Baker's College of Aviation, and many others for great help. And thanks to Fred Kuchem who did the lettering on my Eze and would not take payment, saying he enjoyed seeing it and having a part of it. Along with the N Numbers I had Fred paint along the left side of the canopy beside the front seat, "James Wright, Builder-Pilot", and by the back seat, "Jeanette Wright, Commander".

And my genuine thanks to the "Commander" whose understanding, patience and encouragement were outstanding. And special thanks to the Lord, to whom all glory belongs.



Pilot's eye view out the left side. This is real living!



Jim Ball working with the author as they glass the outside of the fuselage.

Internet and in paint shops. To this, he adds motor oil which is viscous—a handy trait that helps it not fall off the airplane. Then Klaus reduces this mixture with diesel fuel or kerosene, but this combination has too much surface tension. To counteract that problem, he adds a lot of dish soap...One begins to understand exactly how obsessive engineers are about visualizing airflow. (I have found that dish soap makes carbon-black cleanup a breeze.)

Klaus sometimes uses tufts as well. Tufts are small pieces of string that are attached by tape to a surface. In flight, the tufts line up with the air that flows past them. Tufts that stay lined up with the direction of flight represent an aerodynamicist's dream. If they aim elsewhere or bounce around, they show that there is opportunity for airflow improvement. Figure 4 is a picture of Klaus' tufts (while the plane is on the ground) that he used to fine-tune the canard tip shape.

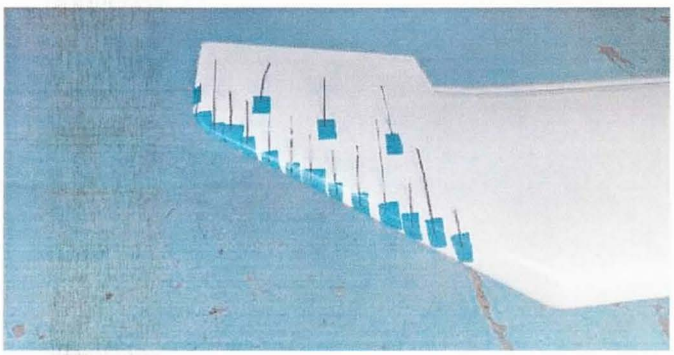


Figure 4: Tufting testing on the canard tip.

There are several reasons that oil flow visualization is more useful than tufts. First, the tufts sometimes fly up above the boundary layer into free-stream air. Second, the tufts can trip the flow from laminar to turbulent, which could affect the airplane's flying qualities and mess up your measurements. Third, tufts only show the air motion when the aircraft is in flight, unlike the oil which stays in place after landing. Finally, tufts are only helpful if you can actually see them during flight. Installing cameras to see the tuft movement in flight is often not feasible. Figure 5 shows the same shaped wing on the ground after a flight with the oil visualization method.

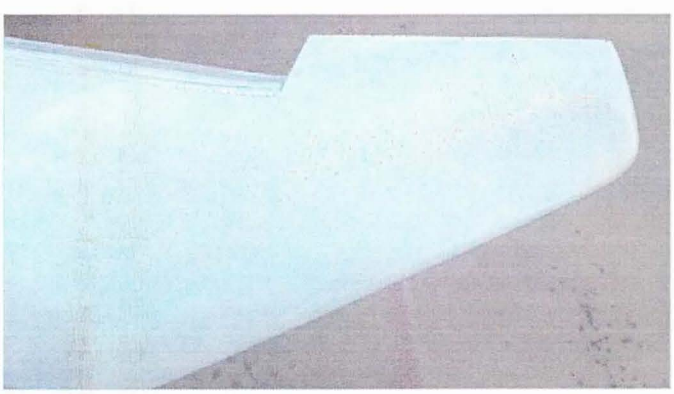


Figure 5: Using oil visualization to determine airflow.

The other method that Klaus uses for flow visualization is impingement. Things in the air can strike the flight surfaces and leave their mark. Most aerodynamicists know about the bug method—if bugs hit the airplane, most of them will slide right off. The ones that hit the plane perpendicularly—at the stagnation point—tend to stick. This bug splat method of flow visualization approach is not limited to wings. Figure 6 shows a duct where the air is supposed to flow smoothly from left to right. The bug splats tell the story: The air is hitting the duct perpendicularly and aerodynamic improvements can be made.

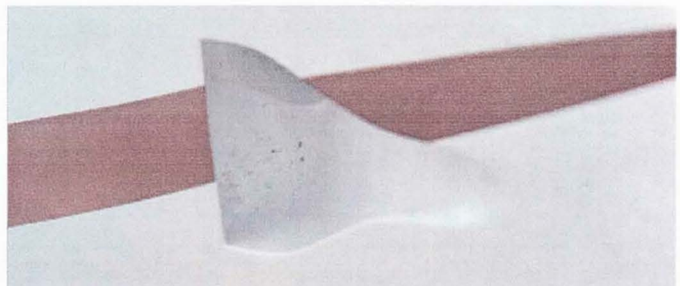


Figure 6: The bugs inside the cooling duct show that the airflow into the duct isn't smooth.

An unexpected impingement opportunity came when Klaus and his co-pilot Jenny Tackabury flew through smoke from a California wildfire. The particles in the smoke rubbed on the freshly waxed airplane. Where there was laminar flow on the forward part of the flight surfaces, the particles slid off cleanly. But the turbulent boundary layer embedded dust particles into the wax. This left the laminar region polished and made the turbulent area dull. As you may remember from my article on aerodynamic devices last month, this transition from laminar to turbulent flow is important to locate.

So Klaus' flow visualization methods let him accomplish step one of the process: Understand the situation. From here, Klaus identified several ways that the air was not flowing efficiently. The following shows some of his improvements which have been designed and tested.

Klaus worked on the cowling first, lowering its profile in order to reduce drag ("it pushes less air out of the way"), and to blank less of the pusher prop. Figure 6a shows Klaus' sleek cowling.

Figure 6a: The Determinator's sleek cowling.

He also made several changes to the Long-EZ's canard. He modified the canard's airfoil, sharpening the leading-edge radius from the standard Roncz airfoil. Klaus decided on the Dornier-style upswept tapered tips instead of the typical Hoerner tip he has on his VariEze, and he modified the elevator's deployment angle. The stock configuration deploys to 25 degrees; Klaus found that after some slot changes, flow stays attached to the elevator all the way to a surprising 45 degrees. "Obviously, making any changes on your airfoils can easily be disastrous," Klaus cautioned. "Increasing the lift capability of the canard—or your tail—can drive the main wing into a stall, and we all know how that plays out!"

He also changed the direction of the gap between the wing and the ailerons. The plans call for the gap to be lined up perpendicular to the wing's swept trailing edge. Instead, Klaus lined this gap up with the direction of flight. This reduced the small drag caused by the edge of the elevator being angled into the wind. He also added a foam insert to the gap to further reduce drag. These changes can be seen in Figure 7.

Figure 7: Aerodynamic improvements to the ailerons.

Note also the accidental flow visualization—some oil remained in the hinges and flowed out during flight. The lines that don't line up with the direction of flight show that there is some spanwise flow. More on that later.

To seal other gaps, Klaus uses a special blue flash breaker tape, as seen in Figure 8. What's so special about this tape? First, it doesn't leave a residue. Second, it doesn't fly off when Klaus races. Third, rain doesn't chisel under the edges, causing the tape to come off. Finally, it's available commercially at some airplane equipment supply shops.

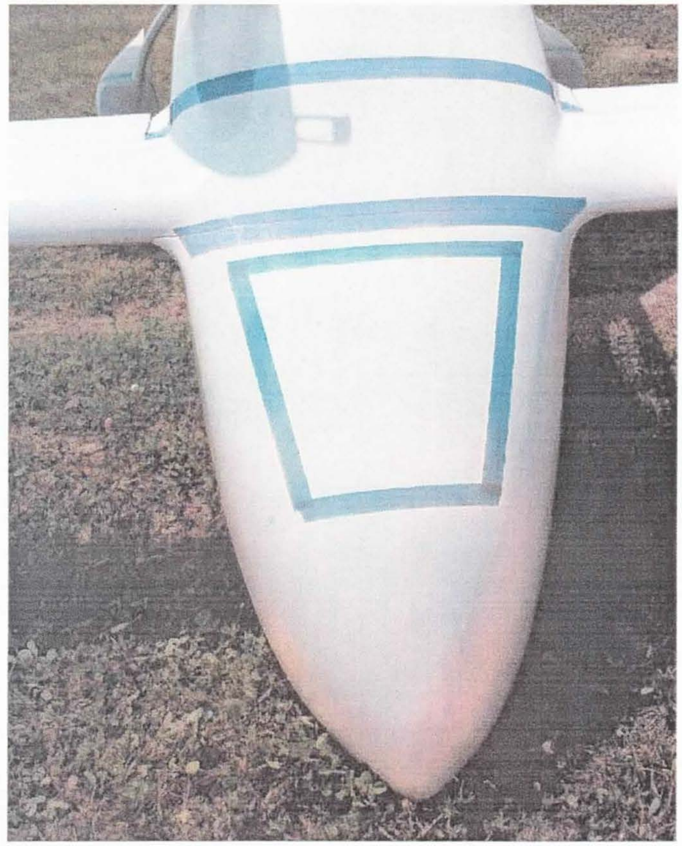


Figure 8: Klaus uses this special blue "flash breaker" tape because it doesn't leave a residue and doesn't come off in flight.

Swept-wing aircraft typically experience flow from the wing root to the tip, especially at high angles of attack. Unless mitigated, this spanwise flow can cause poor stall characteristics: tip-stall; increased landing and takeoff speeds; and pitch-up at stall. Spanwise flow also can reduce control-surface effectiveness and can even blank the areas behind the wing.

To deal with this problem, fences are sometimes used. Fences are typically flat plates that stick out perpendicular to the wing, extending from the leading edge to the trailing edge. They dam up the spanwise flow and shed a vortex at high angles of attack. This can cause the boundary layer to stay attached longer, which can delay stall and improve control system effectiveness.

Vortilons are another tool to battle high angle-of-attack flight qualities. Like fences, vortilons are typically flat plates that stick out perpendicular to the wing. But vortilons extend from the lower surface past the leading edge. Compared to fences, vortilons have less drag in normal flight because of their smaller wetted area.

Here's where Klaus' innovative thinking paid off for him and hundreds of EZ pilots who have used his idea. He looked at fences that cover the entire chord of the wing and thought of a better way. Spanwise flow doesn't just travel along the wing; it flows behind the wing, too. So Klaus shrank the size of the fences and designed them to extend past the trailing

Photography by Lynne Wainfan

edge of the wing. Trailing-edge fences have many advantages over similar devices. They have less drag than vortilons because they affect less of the wing; they have less drag than regular fences for the same reason; they have less wetted area than regular fences; and they are mostly inside the boundary layer.

Figure 9 (and Figure 7) show Klaus' 4-inch-tall trailing-edge fences. Fences can be installed at various locations on a wing, but Klaus' are placed on the wing near each end of the ailerons to increase aileron effectiveness and to reduce spanwise flow, which is highest during aileron deflection. "On swept wings, fences should not be installed on aileron control surfaces since this loads them up to the point that roll authority is all but lost," he cautioned.

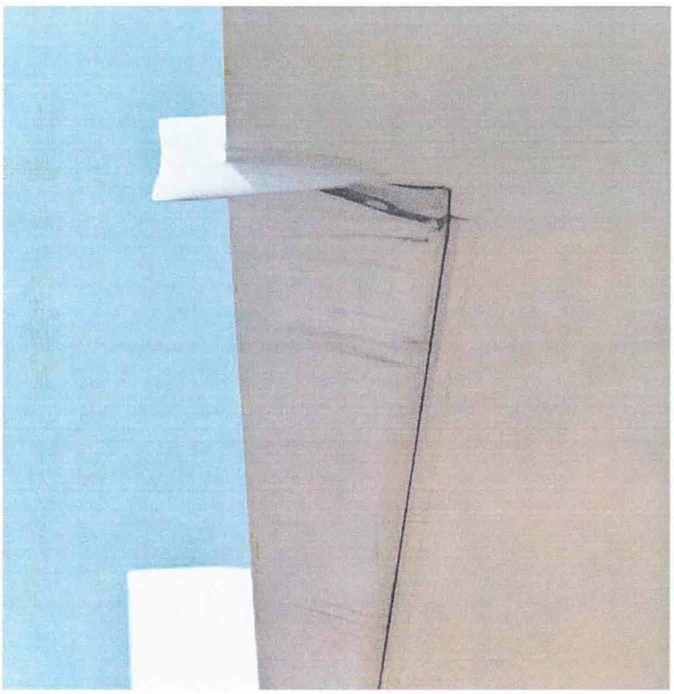


Figure 9: A trailing edge fence.

The trailing-edge fences' effect on low-speed performance was remarkable. Klaus' testing on the VariEze showed "it was immediately noticed that takeoff distance is reduced 10 to 15 percent; climb rate is improved 20 percent; and most noticeably, approaches can be flown at least 10 to 15 percent slower, resulting in a significantly shorter landing distance—nearly 30 percent less. There was a measurable increase in top speed above 10,000 feet."

Recall from my article "Vortilons, VGs, and Fences, Oh My" that it is sometimes helpful to trip the boundary layer from laminar to turbulent slightly forward of where it would naturally transition. Klaus used his flow visualization methods to find the transition zone and the ideal place to trip the flow to turbulent. Figure 10 shows the zigzag tape that Klaus sometimes uses to trip the boundary layer on his wing.

Figure 10: Klaus occasionally uses this zig-zag tape to trip the boundary layer on his wing.

When Klaus oiled up his airplane, he was surprised to find that the transition to turbulent flow was not where conventional wisdom predicted. "Surprise!" he reported. "The transition was at 62 percent of the chord, 5 percent aft of the predicted location of the GAW-2 airfoil. It was way farther back than expected." If he hadn't understood the situation by visualizing his flow, he would have put the zigzag tape too far forward, giving up those precious few inches of laminar flow.

So why did he find that his boundary layer transitioned later than experts predicted? Klaus believes that the turbulence in free air is much lower than in any wind tunnel. Readers are invited to send in thoughts on this potentially important theory.

Boundary layer trippers aren't just useful on wings. Figure 11 shows Klaus' landing gear, with zigzag tape on the strut and wheelpant.

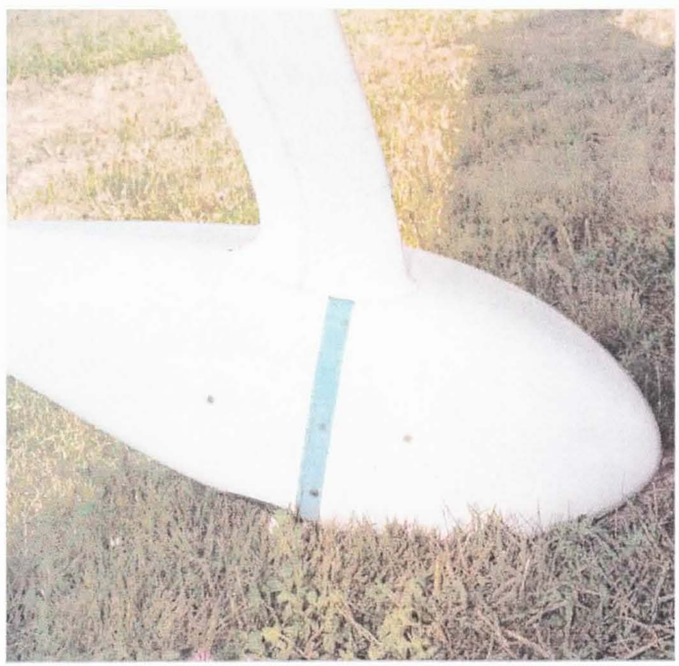


Figure 11. More zig-zag tape on the wheelpant trips the boundary layer there as well.

Although Klaus' plane appears perfectly built, with absolutely no ripple on the wing, his flow visualization revealed another surprise. He said, "On a recent laminar flow test, I noticed that the extent of the laminar flow varied slightly between the two winglets. One has more laminar flow on top (inboard) and less on the bottom (outboard) than the other. This clearly indicates that the installed incident is slightly different."

One of Klaus' remarkable traits is that he is completely honest: He reports his failures as well as his successes; he shows photos of his instruments to prove his performance claims; and he doesn't talk about anything he hasn't done yet. He has an extremely high reputation in the industry for his integrity.

Perhaps the most innovative concept Klaus has come up with isn't even obvious to people looking at the *Determinator*. Other Long-EZs use a so-called NACA duct engine cooling air inlet on the bottom of the fuselage. The NACA duct was invented in 1945 by the National Advisory Committee for Aerodynamics (NACA), a precursor to NASA. It came up with a design for a standardized, low-drag submerged duct, as shown in Figure 12.

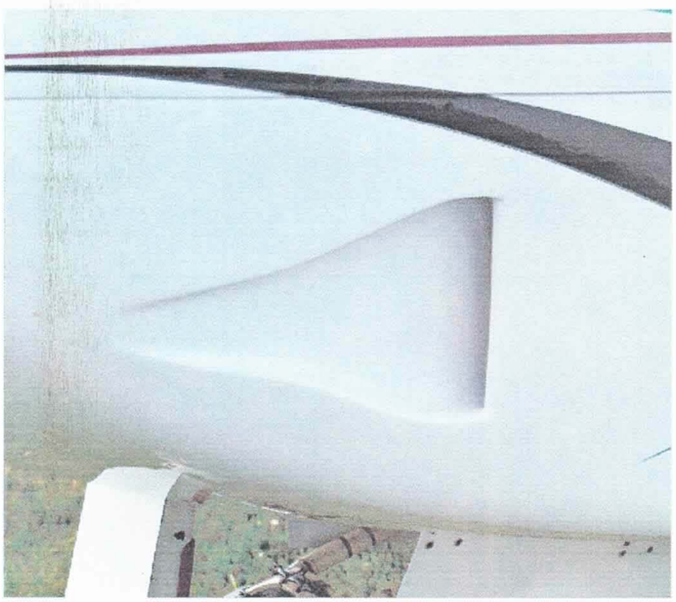


Figure 12: A standard NACA cooling air duct.

The reason the duct starts out narrow and then widens is to increase the area slowly to avoid flow separation. The vertical sides of the duct produce two counter-rotating vortices that roll off the sides and into the duct. These vortices cause more air to move into the duct than normally would.

Klaus looked at NACA ducts that had been in use for 70 years and wondered something: "How do the two vortices created by the duct shape fit into the rectangular opening?" So Klaus played with the shape of the edges of the inlet. Figure 13 shows the duct he flies on the *Determinator*.

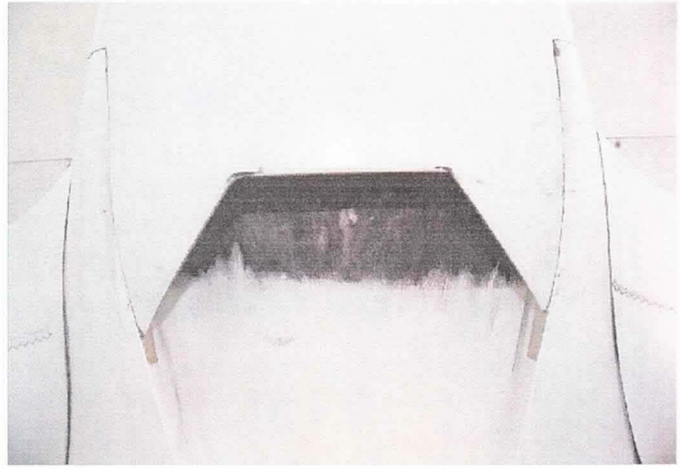


Figure 13: The duct Klaus designed for the Determinator.

The result? Klaus got a two-fer. "I saw an improvement; both a reduction in drag and an increase in cooling," he said.

Aerodynamicists have been known to say that they would sell their grandmother for 15 counts of drag. If that is the case, then Klaus can measure his aerodynamic improvements in deca-grannies!

WEIGHT

Extra aircraft weight costs performance in a number of areas. For instance, the wing needs to develop more lift, which increases the drag. The need for more lift means that the heavier airplane will stall at higher speed than the lighter one. It takes more control authority to get the same angular rates with more weight, especially if that weight is toward the front/back or left/right of the aircraft. Extra weight means more load on structural members, meaning they might have to be sturdier and heavier. More weight might mean a shift in the airplane's center of gravity.

On the other hand, reducing weight arbitrarily could get you into trouble, too. Of course, cutting back on structural elements is a problem, but even cutting back on that wing skin thickness or heavy counterweight could increase the risk of flutter. On the Facetmobile, the two counterweights on the elevons weighed 7 pounds, and they affected the CG of its light, long airplane. It goes without saying (although some should have been told) that you need to know what you're doing if you plan to increase or decrease your airplane's weight.

Klaus naturally applied his methodical, persistent approach to cutting weight on the *Determinator*. For example, when he was changing the injector location, he made an all-carbon-fiber intake plenum. He also built a 9-quart oil sump that weighs 2.1 pounds. The sump alone saved 11 pounds.

Klaus again warns that such engine parts require a specific process. "They should be vacuumed for reduced porosity and only use cured epoxy from an oven at least 300°F," he warned.

Some of Klaus' other weight-saving changes include replacing the plywood and glass firewall with a high-temper-

Photography by Lynne Wainfan

ature foam, carbon-sandwich structure, which saved several pounds. He innovatively combined weight savings and aerodynamic improvements with his wheelpants. "The new wheelpants have the split line at the laminar transition so no zigzag tape is required," he said. "They weigh only 21 ounces with paint and hardware."

Smaller weight-savings opportunities that Klaus took on are too numerous to list. "I put in a great deal of effort to make things light," he said. "But the result was the lightest Long-EZ with a Lycoming IO-360 engine. Most such airplanes weigh in at over 1,100 pounds. Mine is 900 pounds."

THE *DETERMINATOR*'S PERFORMANCE

The *Determinator*, with its propulsion, aerodynamic, and weight improvements, has transitioned beyond what could be considered a Long-EZ. "No engineer would ever design a plane with too much power and too much wing and too little weight," Klaus explained. "It turns out for a cross-country machine, there's nothing better. At high altitude—17,500 feet—it loses only 5 or 6 knots over sea level speeds." Klaus explained that the airplane "plows" less than others; its wing loading is only 13 pounds/square foot so the nose stays down when the air is thin. The *Determinator* wing doesn't present as much area to the wind and has less drag at these lower angles of attack. "Some popular planes with much heavier six-cylinder engines can't even go that high because they just need too much angle of attack at these altitudes," he said.

Klaus says that the *Determinator* is a fast cross-country machine. "A 900-pound airplane with 250 hp does really well at altitude," he said. "It puts out about 250 hp at sea level. Air at 17,500 feet has half the density, so you still have 125 hp at altitude. But at 17,500 feet the drag is halved also. Given the already low-drag airframe, that helps the airplane to go very fast." This speed at altitude gets him to Oshkosh from California quickly. "I've never seen a piston airplane that loses so little speed at altitude."

How fast does the *Determinator* fly? At this year's Bronze Race at Reno, Klaus averaged 263 mph—and that is going around in circles, an inefficient flight pattern. Klaus' average speed documented for the AirVenture Cup was 270 mph. "A few Long-EZs with high-compression piston O-360 engines may top out at 240 mph," he said. The next fastest Long-EZ in the AirVenture Cup averaged 229 mph. Klaus is getting almost 20 percent speed improvement over the next best speed-improved Long-EZ at Oshkosh!

Speed isn't the only performance improvement that Klaus was after. The efficiency-obsessed engineer notes the *Determinator*'s fuel mileage is more than 41 mpg at 250 mph true airspeed above 15,000 feet. This, plus his 49-gallon fuel capacity, allows him to fly almost anywhere in the United States nonstop. Of course, the mileage improves further with reduction of speed, all the way to around 100 mpg at best glide speed. (VBG is where all airplanes get their best fuel mileage.) It is interesting to note that VBG refers to indicated airspeed. Flying at VBG at 17,500 feet adds about 50 mph to your true airspeed! A more stock Long-EZ with an O-360 engine at 220 mph would achieve only 25 to 30 mpg, compared to Klaus' 41 mpg—Klaus burns 64 percent less fuel while cruising 14 percent faster!

The fuel efficiency of Klaus' airplanes surprises most experienced pilots. In 2003, he flew his O-200-powered VariEze in the Reno National Championship Air Races. At the end of the week of racing, as pilots stood in line at the cashier to pay their fuel bill, the other race pilots' jaws dropped with shock and envy: Klaus' bill for the week of flying came to only 17 gallons—and that included the fuel to fly home!

ADVICE

When asked for words of wisdom for other aircraft experimenters, Klaus contemplated for a while. Referencing the time and money he spent making his exhaust heavier, he advised, "It's really important that you don't get too attached to your wonderful ideas. You have to be man enough to take it back out." (An alternate phrase used at Boeing was "You have to be able to admit that your baby is ugly.")

All people who successfully modify their airplanes know that the improvement process—to understand the situation, design a fix, and test the fix—takes some time to master. To understand the situation, you not only have to pinpoint the problem element on the airplane, but you have to understand the *system*—how that one element affects the rest of the airplane in different flight conditions. To design a fix, you have to be knowledgeable about what and how to build and install the improvement. To test the fix, you have to have a well-planned test program, implemented methodically by someone competent to flight-test the airplane. As Klaus' *Determinator* demonstrates, it is possible to modify an airplane to get amazing results. However, it is also possible to inadvertently mess up an important part of the system.

Klaus' final words of wisdom for aspiring aircraft efficiency experts: "Use an abundance of caution."

The cautious Klaus reflected back on his hundreds of ideas to improve his airplane's propulsion, aerodynamic configuration, and weight and said, "I make the changes even though the increment of gain might be so small you might never measure it." Klaus does not have sophisticated instruments or a wind tunnel. But he has the intuition, the expertise, the persistence—plus the determination—to undertake a 31-year improvement effort that gives him unparalleled efficiency and speed. If slow and steady wins the race, then Klaus will win many, many races. EAA

Lynne Wainfan has been a private pilot for more than 30 years. Originally an aerospace engineer, then a manager at Boeing Space, Lynne now consults and teaches at California State University, Long Beach. Readers may remember the Facetmobile experimental airplane, which was built by Barnaby and Lynne Wainfan and Rick Dean.