LAMINAR MAGIC

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Photos Courtesy The Author

"When it comes to speed, there's no substitute for cubic inches," they say. I dispute that saying, and in what follows I will show that by cleaning up your act, literally, you can get more speed for your dollar without buying more inches. This is how it goes:

By increasing the power of a lightplane 50%, one might be able to increase the speed by 14% **if** the aircraft can be held down to the original size and weight. The same 14% increase in speed is gained without a bigger engine if the aircraft is constructed with a 33% lower drag coefficient. A bigger engine costs more; lower drag costs less - remember, what is not there does not cost, does not weigh and does not generate drag. The owner of the big engine aircraft may have forgotten what he paid for the engine, but he will be reminded of his fuel-guzzler each time he meets his sleek aerodynamic friend at the fuel pump. For a majority of little guys in the EAA, an assault on air drag will likely have more appeal than an assault on our checkbooks. Nice words, but what if present day lightplanes already have reached their ultimate aerodynamic performance? Well, apart from the fact that in human endeavor nothing is "ultimate", we better take a critical look at modern lightplanes. How, for example, do they compare with other means of transportation? How are other "transports" doing the job for which they have been designed? How much friction or, generally, DRAG (D) must other "transports" overcome to move their LOADS (L)? In other words, how good is their LOAD over DRAG, or for short, L/D performance ratio? Some very approximate numbers: a horse pulling a single axle cart can transport, say, a 10 lb. load for each pound of pull with which it fights the friction (= DRAG) "D". The horse cart L/D is 10. A car may experience, depending on its speed, something like L/D = 100. A ballbearing alone can have an outstanding L/D = 1,000. A well designed and maintained ship? A L/D = 10,000 is not impossible.

The Cessna 150/152, one of the world's most numerous lightplanes, displays some (LOAD = WEIGHT = LIFT!) L/D = 12 and good composite sportsters are just a little bit better, L/D = 12. Don't you think that present day aerodynamicists and designers should wake up and begin **seriously** doing their homework? While this critique neglects the fact that aircraft move faster than cars or ships, it should be remembered that they move in a very "thin" medium, experiencing a friction that is only a small fraction of that of water (or the road). No, there are just no excuses for a "modern" sportplane to behave like a cart behind a horse. If such is the shape of present day light sportplanes, then we must still be very far from having exhausted all engineering possibilities. An interesting field is obviously wide open here! Soaring people are already playing with the idea

Laminar Magic in its original configuration, with a 2-cylinder, horizontally opposed engine. Note the arrays of "suction" holes at the end of the pod . . . to create a slight underpressure in the cockpit.

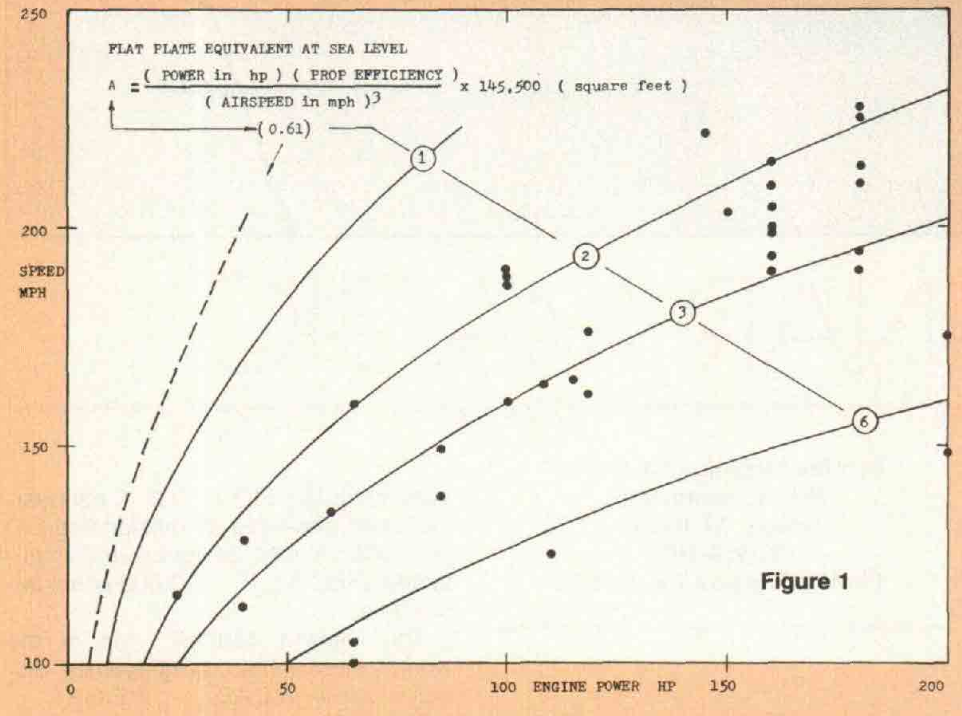


Figure 1

of L/D = 100 sailplanes of the future. If we could reach that same goal of L/D = 100 in our powerplanes, our 600 pound single-seaters would generate an air drag of 600/100 = 6 lbs., requiring only some 4 hp to fly 200 mph. We realize the situation is much more complex and considerably less favorable in airplanes than it is in sailplanes. A L/D = 100 is not within our reach for the next 10 or 20 years. However, between the L/D = 12 of a Cessna 152 and the L/D = 100 of a future sailplane, there exists an enormous amount of information, just waiting to be "discovered" and applied. The homebuilder, willing to enrich his original ideas with research results published by NACA, NASA and many other sources, has every chance to come up with an improved, "low drag" aircraft.

ONE SQUARE FOOT?

How much performance - speed - do present day lightplanes owe to their engines and how much to their good aerodynamic shapes? To put it simply, we need to know their **flat plate equivalents** (the size, usually in square feet, of a ficitious plate, positioned perpendicularly to the airflow which, moving through the same air with the same speed as the aircraft investigated, would generate the same amount of drag as the aircraft). Not a perfect method, but very convenient if we know airspeed, power at which that airspeed was flown and propeller efficiency. In high power, kitplane factory manufac-

DEVELOPING THE EQUATION FOR THE FLAT PLATE EQUIVALENT

In general, using P for power in hp
v for speed in mph
rho (ϱ) for air density (at sea level = 0.00238) slug/ft^3
A for the flat plate equivalent area in ft^2

we have P (550) = v (DRAG) (1.47)

(550 being the conversion from hp to ft-lb/second and 1.47 from mph to ft/second)

DRAG can be expressed as DRAG = ½ (rho) v^2 $(1.47)^2$ (A)

Combining this equation with the one above for power we have:

$$P (550) = v^3 (1.47)^3 (\tfrac{1}{2}) (rho) (A)$$

Now this is the aerodynamic power delivered BY THE PROPELLER. The engine (brake) power is lowered by the propeller efficiency:

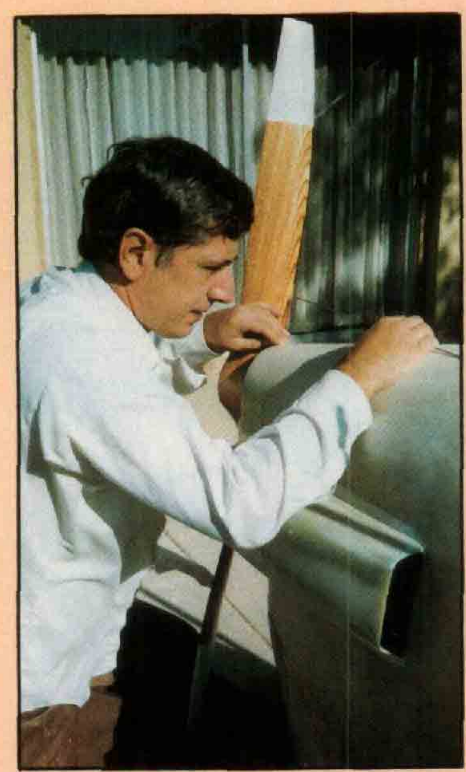
$$P (efficiency) (550) = v^3 (1.47)^3 (\tfrac{1}{2}) (rho) (A)$$

from which it follows, if we take air density (rho) at sea level:

$$\text{A in ft}^2 = \frac{\text{(POWER in hp) (prop efficiency)}}{\text{(AIRSPEED in mph)}^3} \times 145{,}500$$

tured aircraft, propellers are often metal and constant speed, with a possible efficiency of 85%. Low power, amateur built aircraft usually have wooden, fixed, sometimes homemade propellers where anything better than 70% is a success. Speed and power should be known as accurately as possible if the flat plate equivalent is to become a useful tool in evaluating aerodynamic "cleanliness" of an aircraft. It is the best to use data from some reliable competition or from races, taking into account that pylon races do not allow top speed in a straight line to really show up. While the speed can be known with a good accuracy, the power used during the racing is not. For example, an aircraft the engine of which has been officially entered as a 100 hp unit, but has been "souped-up" to 130 hp, can perform apparent miracles of efficiency to the unwary - until you enter the **real** power into the equation for the flat plate equivalent. FAI (International Aeronautic Federation) which registers and supervises all world records from ultralights to lunar landings, does not check the engine power (too easy to cheat and difficult to measure), controlling instead the gross weight, speed and distance.

Figure 1 shows the speed and horsepower of a number of homebuilts that have competed in the "Sun 60" air race at Sun 'n Fun the last 3 years. Kitplane manufacturers' own aircraft are not included, for obvious reasons, and neither are some others with unclear data. The four full curves indicate flat plate equivalents of (1), (2), (3) and (6) square feet. The curves were calculated from the equation at the top left of the diagram, assuming a propeller efficiency of 85%, thus doing some injustice to low power homebuilts. It is seen that our best homebuilts possess flat plate equivalents equal or slightly less than 2 square feet. As a point of theoretical interest, what should be the flat plate equivalent of an "ideal", all-out, cost-no-object, single seater? Calculations and discussions published in the book "Low Power LAMINAR AIRCRAFT DESIGN" (see ad in Classifieds/Books) say such an aircraft, flying 200 mph on 40 hp would have an equivalent drag of 0.61 square foot. This value is also plotted on Figure 1 (broken line). Estimated cost of the project - $100,000. In his far reaching article, **Laminar Lightplanes** (Sport Aviation August, September 1976), Bruce Carmichael introduced to us homebuilders the promise of great improvements "laminar" aerodynamics holds for the light aircraft. The reader may want to compare Bruce's visionary design examples with the project described in this article. Even today, 14 years later, Bruce is ahead of the rest of us!



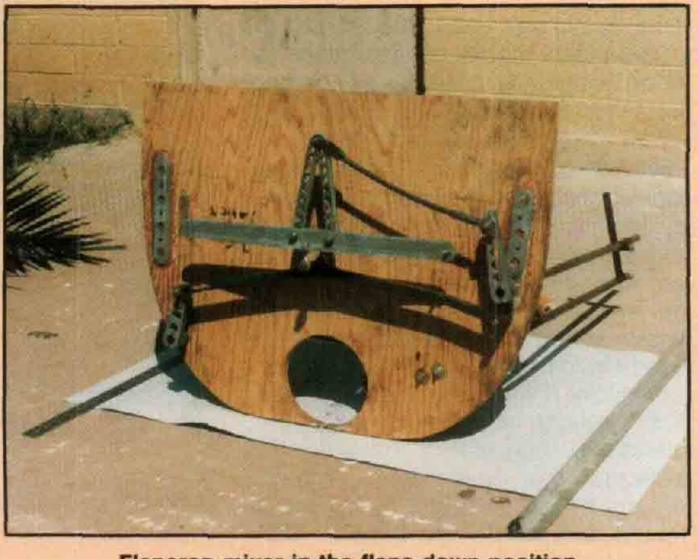
The author's son, Ales, designed and tested the internal and external airflow systems around the engine . . . critical in a pusher configuration.

A brief glance at Figure 1 shows that an aircraft generating the drag equal to that of one square foot plate would fly 180 mph on 50 hp, 230 mph on 100 hp, almost 300 mph on 200 hp and, if you will forgive me, more than 100 mph on 10 hp. I fully understand if you find this magic 1 square foot impossible, a dream of an "armchair designer", out of touch with reality. After all, how can an entire airplane, fuselage, wing, tail surfaces, landing gear, antenna, etc., generate only as much drag as a plate the size of this page? Well, unlike the above mentioned 0.61 square foot, our analyses show that one square foot is possible with a very carefully conceived single seater, rigorously applying rules of "laminar" aerodynamics. Without compromising pilot safety or his comfort and without requiring special materials or complicated building methods. Difficult, but possible. A tremendous challenge for any designer, big or small, as there will be a long, long way from first paper computations to that eventual honest "one-square-foot" flight! Next century (it starts only 10 years from now, my friend!) will bring it for sure. We will attempt it **NOW**.

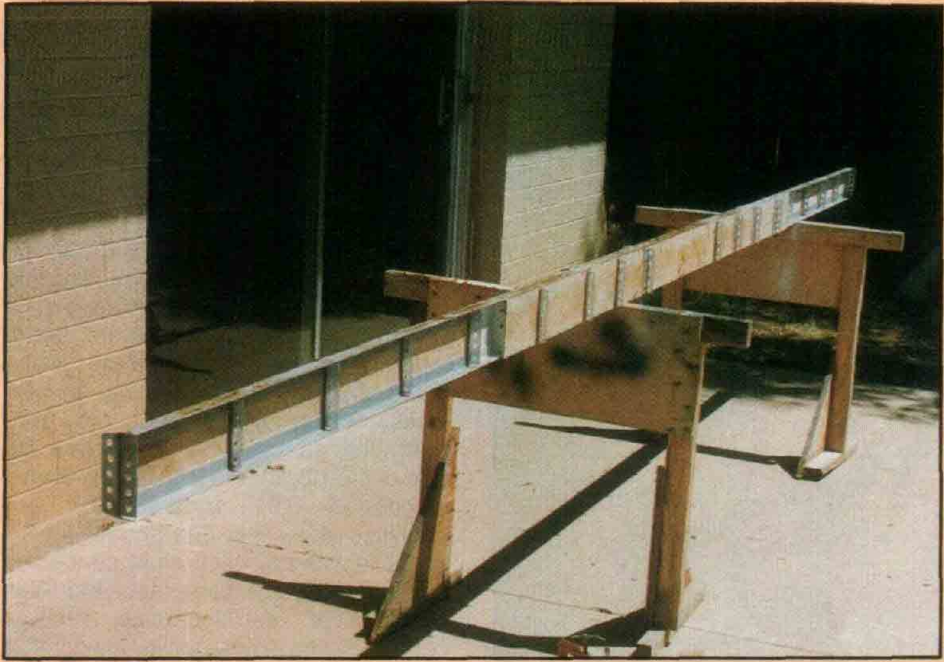
GENERAL CONCEPT

The first step in designing a low drag airplane is the establishment of a laminar flow over as large a part of its "wetted" surface as possible. The wing and tail surfaces must sustain laminar flow along 50% of their chords and the fuselage must stay "laminar" at least the first 30% of its length. The landing gear must disappear. It goes without saying that any protruding control horns, pitot tubes, hinges, triangular (stall) nose blocks, fuel tank caps, screw heads, rivets, antennas and lights immediately

Flaperon mixing unit . . . shown in the flaps up position. The side stick assembly extends forward at the right.



Flaperon mixer in the flaps down position.



The wing's main spar consists of 2024-T3 aluminum angles bonded to a plywood web. No bolts, no rivets.

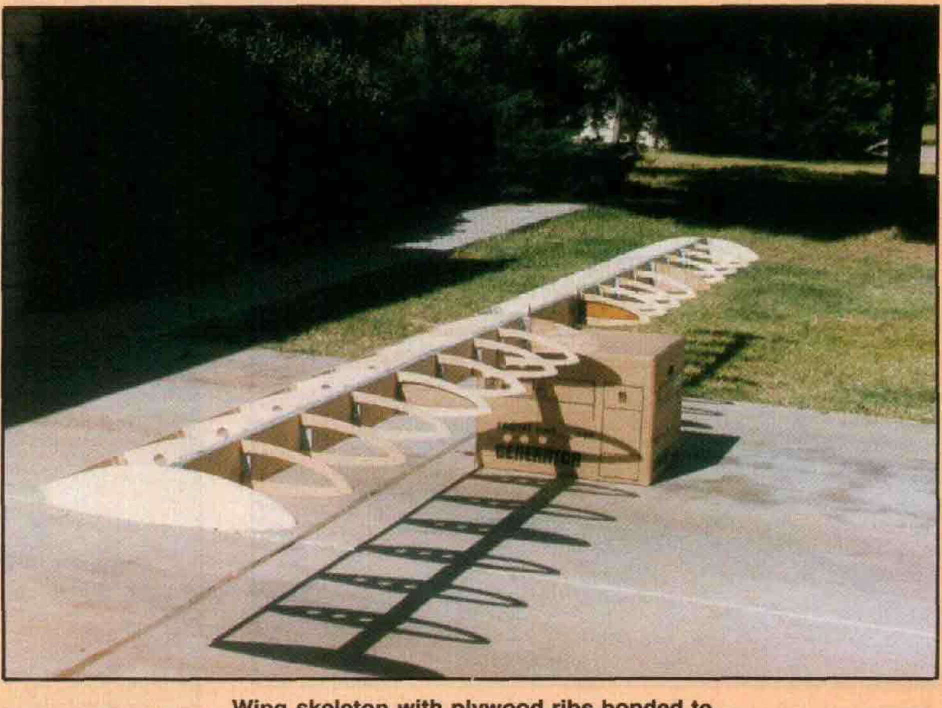
destroy laminar flow and leave a widening path of turbulent wake behind. The fuselage and wing noses are particularly sensitive - the boundary layer is ony a few hundredths of an inch thick here - so nothing that could irritate laminar flow is allowed in these areas. This, of course, automatically requires the removal of the propeller from the fuselage nose, leaving the designer with the unpleasant task of finding a new, less damaging place for the powerplant.

Keeping in mind that even a perfect laminar shape leaves at least 50% of the wetted surface immersed in turbulent flow and that the laminar part is not without frictional drag either, the next step is to minimize this total wetted surface. For a "90 percentile" pilot to fit comfortably in a reclining seat, a cockpit 2 feet wide and about 3 feet high has been found quite adequate. It produces an approximately elliptical frontal area of 4.7 to 4.8 square feet, which is also large enough to accommodate the engine and a fuel tank. With the frontal area fixed, one finds that among the conventional aircraft configurations (no flying wings, no canards, no helicopters) the pod-and-boom configuration offers the smallest wetted surface.

Unlike wing sections, "laminar" fuselage shapes have not been investigated systematically, probably because in those good old times bigger "cubic inches" were easier to come by than "laminar" research. Some sailplanes, always years ahead of powerplanes, simply used coordinates of good wing sections - basically a weak step, the flow along the fuselage being much more 3-dimensional than that of the wing. The fuselage-wing interference problems did not help then and they still cause headaches today. The famous "3/2 - power" rule seems to be gaining ground these days in top notch fuselages, especially when reinforced by a strong constriction of the fuselage cross section immediately past the wing-fuselage disaster area. The reader interested in this rather recent chapter of "laminar" aerodynamics may consult the author's book, "Low Power LAMINAR AIRCRAFT TECHNOLOGIES", the only source we know of that more systematically handles high performance "laminar" fuselages.

The pod-and-boom configuration chosen for the S-4 Laminar Magic is an example of the fuselage construction pushed to the extreme. In addition to a small wetted surface, the relatively short pod better fits the ideal laminar body shape than the conventional (long) fuselages do. A good fit of the flat wrapped-around canopy is essential. The unavoidable airflow out of the cockpit into the sensitive area just in front of the wing/fuselage junction is prevented in the Laminar Magic by a slight underpressure created in the cockpit by an array of suction holes visible at the trailing edge of the pod. By the time the airflow has passed the wing/fuselage junction, it invariably turns turbulent. This region, all the way to the end of the pod, is a good place to install the engine and all the "dirt" that comes with it, because the boundary layer grows fast here, reaching some 1/2 inch at the vertical trailing edge of the pod. The remaining part of the fuselage consists of a square boom, some 3-1/2 x 3-1/2 inches in size. Positioning of the boom at the bottom of the pod serves to protect the propeller, acts as an accurate construction jig for the installation of the bulkheads and of the tail structures and allows all the controls and the antenna cable to run in a single straight line from the tail into the cockpit. Some homebuilders will question the correctness of selecting a square boom in a laminar aircraft, and they are right. However, if one considers the turbulent wake behind the "huge" pod (the cross section of the boom is only 2% of that of the pod), especially the wake produced by two partly protruding landing wheels, one can easily visualize the tiny boom being **immersed** into that wake. This immersion, as we will show shortly, can drastically reduce the drag.

Perhaps the best part of the S-4



Wing skeleton with plywood ribs bonded to the small aluminum angles on the main spar.

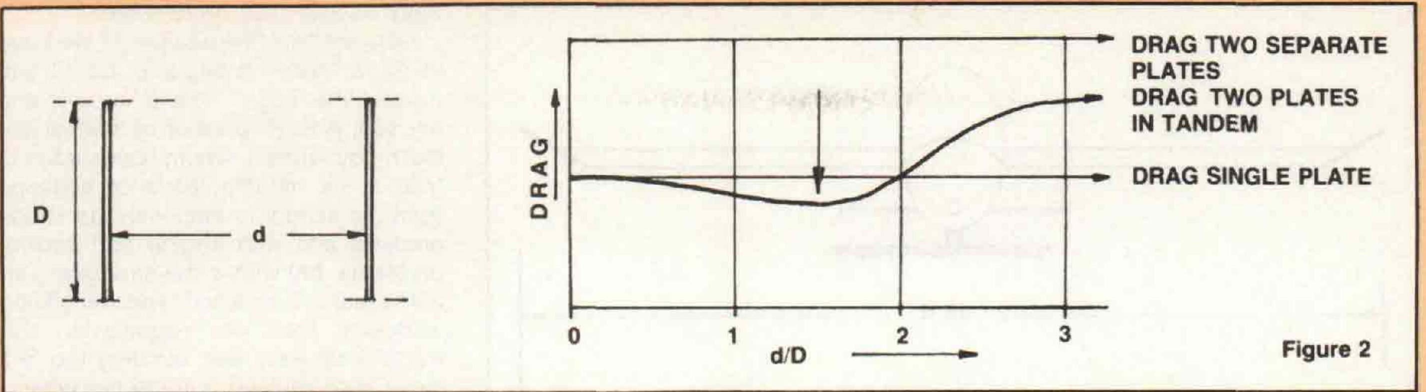
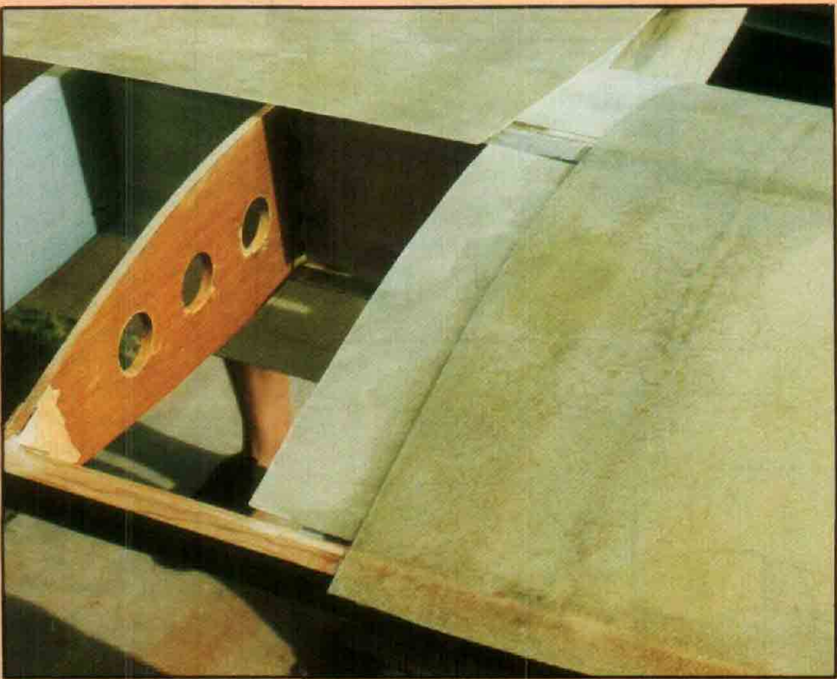


Figure 2

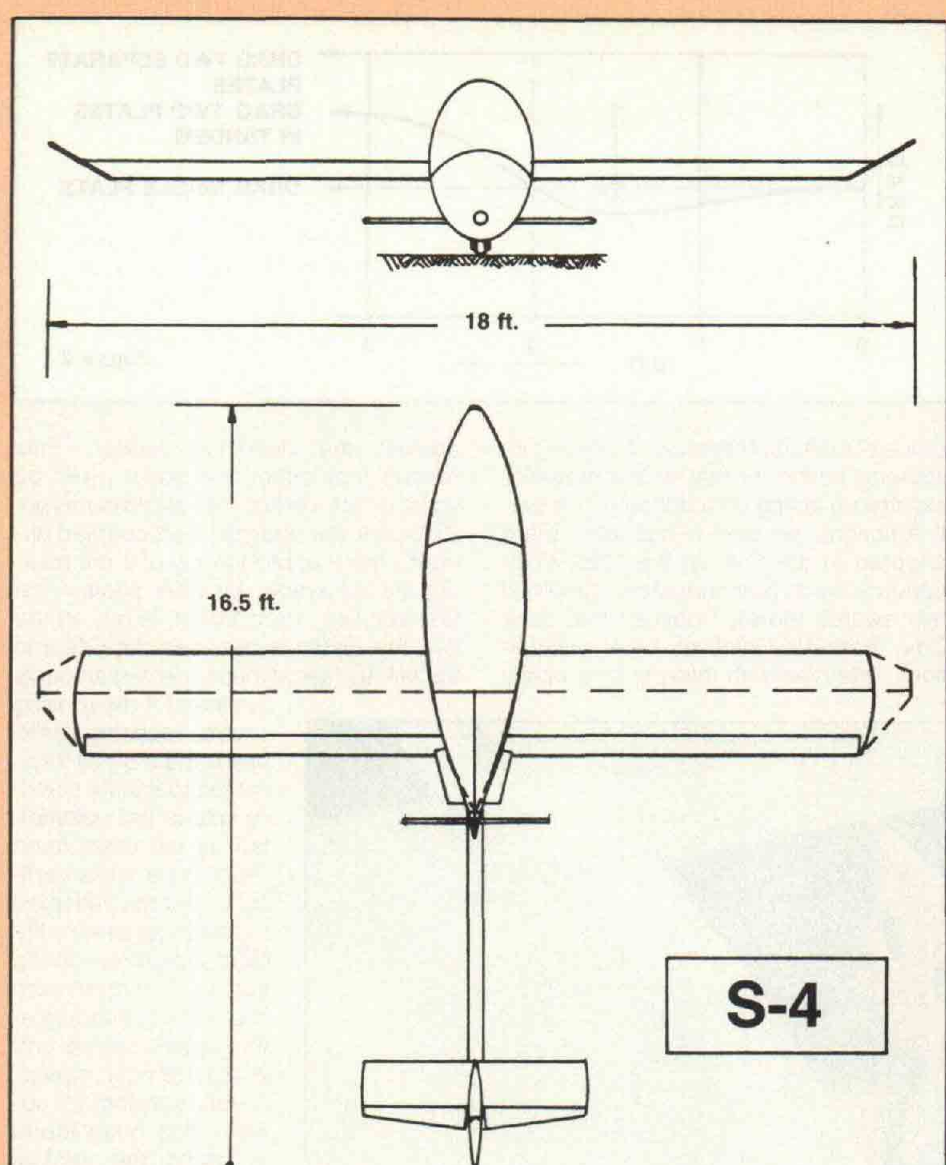
Laminar Magic design is an apparently strange cooperation between the landing gear, the square boom and the tail surfaces. First a wind tunnel experiment - when placing two flat plates (diameter D), Figure 2, perpendicularly to the airflow a large distance (d) apart, their total drag equals the sum of the independent contributions of each plate. As the distance (d) between the plates decreases, the second plate enters the wake of the first one and, finding itself in a slower, decelerated flow, experiences a **reduced** drag. The real surprise comes at a certain separation (d/D = 1.5) (arrow) when the total drag drops to **less than that of a single plate**. What happens here is that the wake of the first plate combines with the wake of the second, creating a flow around the plates that roughly resembles the flow around a cylinder with its axis in the direction of the flow. Such a cylinder has considerably lower drag than a flat plate of the same diameter. Readers are familiar with this phenomenon from (illegally) driving their car very closely behind a large, box-like truck or from watching those motorcycle/bicycle races where the cyclist, following the motorbike very closely, reaches astounding speeds. We first applied this idea in the design of the S-2 motorglider (see **Sport Aviation**, April 1982). The surprisingly good performance of the S-2 (the only garage built motorglider in the world that flew, under controlled conditions, to International FAI Silver, Gold and Diamond Badges) is to a large extent due to an almost negligible drag of two half submerged and closely spaced **fixed** landing wheels.

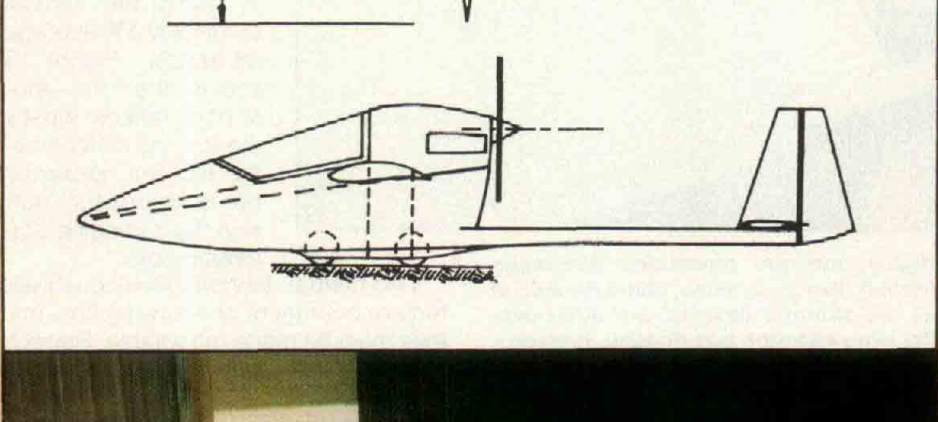
In the S-2 we wanted to get rid of that troublemaking, ugly tailwheel, a disgrace of most motorgliders, replacing its steering action by that of the propeller slipstream acting on a deflected rudder. It functions so well it has also been adopted in the S-4. At the 1989 Copperstate Fly-In (Laminar Magic received two awards there), I noticed that Jack Cox, Editor-in-Chief of EAA publications, watched with interest how easily Laminar Magic turned around corners on its way to the runway. However, we are now facing a problem we did not encounter with the S-2. In order for our landing system to work properly, the slipstream must **efficiently** work against the deflected rudder. This means that either the boom must be short or the vertical tail relatively large. Since we are against short-coupled aircraft - there are too many of them making life miserable for their pilots - the first solution, short boom, is out. In the S-4 the distance between the CG and the tail AC (aerodynamic center) amounts to almost 4 mean wing chords, requiring on the one hand a small vertical tail to satisfy stability criteria (tail volume), but on the other hand requiring a large vertical tail for the deflected rudder to generate sufficient side force during taxiing. The slipstream is already spreading at this large distance and is also losing its speed. A very satisfactory solution has been found in giving the vertical airfoil only 5% average thickness. Figure 3 shows that the slipstream strikes mostly the top, thinnest part of the fin. The horizontal tail is completely outside the damaging slipstream core.


Highly accurate premolded Wortmann (airfoil) fiberglass skins, characteristic of all the author's designs, are fitted over the wing skeleton and bonded in place.

Two central, tandem, landing wheels require outriggers on the wing tips, and they must be made retractable. Retracting a 3/8 inch steel rod with a 3 inch wheel at its end should not be a problem, nevertheless we decided to make our first taxi and flight tests with the outriggers fixed. We have a new, unproven aircraft on our hands and we feel that we do not need any new problems, as


Figure 3





Fuselage skeleton consists of 4 plywood bulkheads sitting on a wood/plywood boom.

easy as they may be to solve.

Now we have the design. All we have to do is build the airplane, test it and remove the "bugs". "We" is my wife and my son, Ales (Professor of mechanics, thermodynamics), whom I persuaded to take a six months leave of absence from his school to help with the stress analysis and with engine and cooling problems. My wife is the strongest part of the team. Ever since I was her gliding instructor back in Yugoslavia, she would help as I was building the S-1 flying wing, helped pull me out when I crashed it, would later assist in building, inspecting and assembling the S-2 motorglider and at the airport would keep notes and records of our tests. Her "Oh, no, you don't!" would lift my spirits numerous times when I was crushed by "unsolvable" problems and was ready to quit. I hope that you, too, have such a permanent partner because we are weak without them.

THE ENGINE

Initially we selected an expensive Italian "aircraft" engine . . . two-cycle, 30 hp with two opposing horizontal cylinders. With a reduction gear and an electric starter, it weighs less than 50 lbs. Unfortunately, unlike snowmobile engines that are flooding our light aviation market, our engine does not have a built-in cooling fan and we know that we have a problem here. If the pusher configuration has any weakness it is the inability of the propeller to provide cooling air for the cylinders. In our case it is not enough to construct efficient **inner** air ducts and baffles; partly they will be laid on the **outside** and it is here that they may cause flow disturbances. Manufacturer-supplied baffles help a little; nevertheless, it takes Ales one full month of calculations and trials to come up with a solution that simultaneously guides air to the carburetor and to cylinders, slowing down the flow where necessary, and provides a necessary control of the outside airflow. We also ask Bernie Warnke to slightly reshape his propeller such that the area close to the hub also participates in the suction of the cooling air. Testing confirms our expectations and at that stage we feel that final success is just around the corner. At the airport the aircraft is weighed. At 284 lbs. it is barely exceeding the legal ultralight weight limitation (254 lbs.).

We begin with slow taxiing to get acquainted with outriggers. Happily, we note that the engine responds eagerly and that it never overheats. Then, one hour into the testing, according to the Hobbs meter, one of the starter gears breaks. How could we have done anything wrong? Fortunately, I am always on the ground when starting the engine.

We complain to the U. S. dealer and buy a replacement. At 4 hours on Hobbs, both gears on the starter break and have to be replaced. Same place, twice? In engineering we do not like these sort of coincidences. At 7.2 hours (Hobbs) we discover that again a gear broke, however, upon opening the starter area we see that this time an entire part of the electric starter broke off as well. Before we were flabbergasted, now we are angry. If you saw the material this part was made of, you would be, too. The manufacturer explains that all major European motorbike manufacturers use this Spanish electric starter. I am used to Bosch starters so I know how a starter should be put together, especially if it is built into an "aircraft" engine. We send the engine to the dealer, however, upon learning that the repaired engine was not test run before returned to us because they "do not have the proper means to run engines", we decide to scrap the engine. Now I am a couple of grand poorer and without the right engine, the project has come to an early end. Thousands of manhours for naught. I am not rich . . . it hurts.

A NEW SPEED RECORD

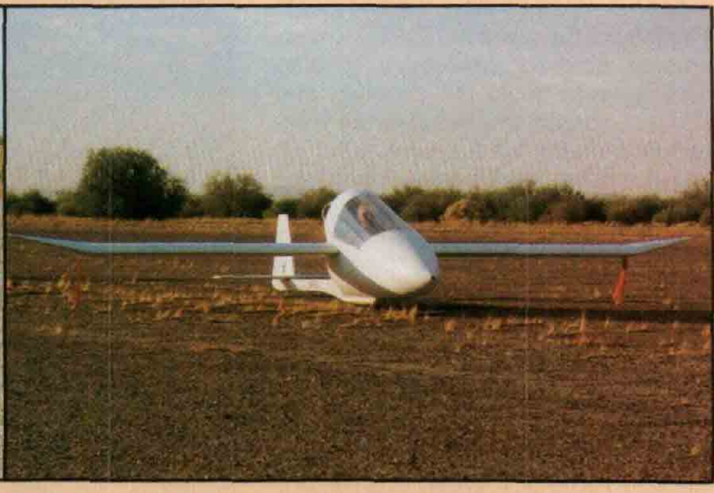
Then my wife comes up with an idea. Couldn't we, temporarily, borrow the Kawasaki engine from the prototype S-2 motorglider and try it on the S-4? Now, the Kawasaki is *not* an "aircraft" engine; it is an ex-snowmobile engine, but it is sturdy and reliable. It has NEVER let me down, no part of it ever fell off. Quick calculations indicate that it just might do.

Now comes the unpleasant job - removing the old and shaping a new cowling for the Kawasaki, new supporting structure, new air inlets, new everything. The worst part - propeller. In the S-2 we did not have a reduction drive; the propeller ran at some 5,000 to 5,500 rpm, with its tips close to the speed of sound. The engine may develop 25-30 hp in this rpm range. At the 5,000-5,500 rpm range, efficiency of wooden, 100 mph propellers operating on 25-30 hp is very poor, down to some 50%. Main culprits are thick wooden blades, in particular at the tips, where about 80% of the noise is generated by high subsonic tip speeds. In the S-2 motorglider low efficiency did not matter much - the main demand was a high soaring performance. Now it matters. Yet, a 50% engine is still much, much better than no engine. And, besides, if we have designed Laminar Magic as well as we think we did, it should fly faster than any of its equals, no matter what the propeller efficiency. Remembering those optimistic speed claims we sometimes find in the aviation press, we decide that nothing short of a 3 kilometer speed record attempt will do. NAA (National Aeronautic Association, official representative of the FAI in the U. S.) sends detailed instructions and nominates John Nelson, former president of our EAA Chapter 598, as Controlling Official. Six timers and a number of outside official observers must occupy proper posts at proper times, official scales must be accurate to within grams . . . I am beginning to feel like the organizer of Olympic Games. Flying will obviously be the easy part - all you do is hold the stick steady over those 3 kilometers. A young ultralight pilot - it does not hurt that he also flies at Mach 1 - is given the honor to try for the record. We teach him how to turn while taxiing and after a few attempts and a few short "jumps" along the long runway he is ready to go around the airport and later to try the aircraft at altitude.

Fuselage pod is covered with plywood, followed by fiberglass.

On September 16, 1989, First Lt. John Washington, USAF, flies 126.7 mph . . . about 10 mph faster than the existing world record in the Class C-1A/o, piston engine, under 661 lbs. gross weight, according to the official NAA World Record Book. On September 27, 1989 we are informed that NAA officially approved the 126.72 mph as a new 3 kilometer National Record. John flew the record at 5,500 rpm, indicating 30 hp engine power. Plugging 30 hp, 126.7 mph and 50% efficiency into the equation on Figure 1 gives an equivalent flat plate area of 1.07 square foot. It seems we will not have to wait for the next century.

What next? How about an ultralight (= 254 lbs.), ultra clean, fast motorglider, a sort of Laminar Magic Mark II, with an engine capable of driving an 85% propeller? Can you estimate (using Figure 1) what speed to expect at 30 hp and outriggers retracted? This aircraft could be designed and built by YOU. I am sure your workshop is as good as my garage, your hands as good as mine and you could take care of details that we have missed. Worth giving it a try? After all, who says that only people over 68 - like me - should go after speed records?



Laminar Magic, right, with its 18 ft. span and its ancestor the S-2 motorglider with a 50 ft. span.