

Fuel & Fire



Fuel injection
and ignition, old
school and new
cool, same day,
same dyno.

BY DAN HORTON

Some days I love this job. Not all of them of course. Like the other wrenches I've spent a few fine airport days holed up in a dim room, staring at a computer screen, banging out a story. It's the price paid for the great days...the ones spent turning 100LL into noise and velocity, heat and RPM.

This story begins with a fellow named John. John Walker is a lucky pilot who recently acquired a beautiful wife *and* in-laws who love airplanes. The new family project is an RV-10, which of course, requires an engine. That brought Walker to Barrett Precision Engines (BPE), the highly regarded shop in Tulsa run by the brother-sister team of Allen Barrett and Rhonda Barrett-Bewley.

Walker makes his living in high technology. It's no surprise that he would be an "early adopter," as defined in the classic work *Diffusion of Innovations*; one of the roughly 13% who try new things before the rest of us. Although pilots generally accept new technology, we tend to be, on the whole, very conservative in our critical choices. Most of us stick with the proven and the familiar. Not so the early adopter, who considers the value of the new, and judges it to be worth whatever it might cost.

The engine technology that caught Walker's interest was the EFii-branded electronic fuel injection and ignition package (www.flyefii.com) offered by Robert Paisley of Protek Performance.



The gearheads: Monty Barrett, Allen Barrett, John Walker, and Robert Paisley.

Paisley, a Cal Poly electrical engineer, has a long history in aftermarket ignition products, beginning with Dyna motorcycle ignitions, and later operating DynaTek from 1991 until selling the company in 1999. He started a Van's RV-7 kit in 2001, flew it to Oshkosh in 2003 with Eggenfellner Subaru power, then spent many years sorting out various Eggenfellner engine configurations as an independent West Coast representative of the brand.

EFii systems are offered as single or dual electronic ignition kits, or complete electronic fuel injection/ignition kits with single or dual ECU. Walker selected dual EI/EFI, which replaces both magnetos, and the entire Bendix or Airflow Performance constant-flow mechanical fuel injection commonly used on an IO-540. Among other advantages, the system is billed as offering more power, smoother operation, less fuel burn, and less weight.

BPE was contracted to build the engine. All engines produced at BPE are installed on the company's Kahn water brake dynamometer for testing and initial break-in before delivery to a customer. The Barrett dyno first became operational in 1994, and at that time was arguably one of the most advanced in the aircraft engine business. It documents 35 channels of run data, and every customer gets a printed record.

Enter the Gearheads

Allen Barrett, like any business owner, is charged with looking ahead and considering the future. In his opinion, it is only a matter of time before electronic systems replace older mechanical systems, in particular on the many Experimental and high-performance engines built for BPE's sport and aerobatic customer base. It may not happen overnight, but there is certainly a trend. For Allen, the issue is selecting which EFI and EI systems to support. Not all of BPE's experience with electronic ignition has been satisfactory, so much so that they often do their dyno runs with standard magnetos; customers are free to install a personal ignition choice later. A locked-down magneto allows certainty about engine ignition timing, critical when a great many dollars are spinning at 2700 rpm on the other side of the dyno room's glass wall.

Barrett was very interested in gathering experience with Paisley's EFii system, as was his dad, legendary engine guy Monty Barrett. Monty tried to retire some years ago and build a Pitts Model 12. That lasted until he took delivery of the required Vedenev M-14 radial and got curious about



Allen Barrett makes an adjustment. The big silver box over the engine is an air hood. A 25-hp electric fan ensures enough cooling air supply.

what might be inside it. In the end, he un-retired himself and developed a complete M-14 rebuild program for BPE, including an additional dynamometer dedicated to the radial, and Russian factory tooling. Neither Barrett is averse to electronics. When it became evident that the supply of parts for the Soviet M-9 magneto was unreliable, the Barretts spearheaded the development of a complete coil-on-plug dual electronic ignition for the radial.

Robert Paisley is no stranger to a wrench, having spent all those years in the ignition business. Paisley earned a lot of respect while sorting out more than a few flying Subaru issues. He famously staged a speed contest which pitted his turbo Soob against an IO-360 powered RV-7 at 8000 feet (he won), as well as a static thrust comparison with all comers (he won again). Paisley definitely qualifies as a bona fide gearhead.

When I heard about Walker's engine, and knowing the test procedures at BPE as I do (full disclosure; I'm a Barrett customer, a friend, and yes, a gearhead), I couldn't resist a proposal. Frankly, given everyone's background, it was an *irresistible* proposal. We would break-in the new

RSA10 - SLICK MAGS							EFII INJECTION AND IGNITION							
WOT 28.1/2700 CORRECTED HORSEPOWER 278							WOT 28.2/2700 CORRECTED HORSEPOWER 265							
PARAMETER	BARO	RH	IAT	BHP			BARO	RH	IAT	BHP				
OBSERVED VALUE	29.9	52	89	259			29.9	52	103	249				
CORRECTION	1.0077	1.038	1.0275	259			1.0077	1.0216	1.0405	249				
24°/2700 CORRECTED HORSEPOWER 234							24°/2700 CORRECTED HORSEPOWER 221							
		RH	IAT	BHP					RH	IAT	BHP			
		52	91	201					51	103	199			
		1.038	1.0254	201					1.0208	1.0405	199			
19.5°/2700 CORRECTED HORSEPOWER 131							19.5°/2700 CORRECTED HORSEPOWER 148							
		RH	IAT	BHP	ChP				RH	IAT	BHP			
		51	92	142					29	104	139			
		1.0355	1.0303	142					1.0195	1.0414	139			
24°/2400 CORRECTED HORSEPOWER 134 FF 16.3							24°/2400 CORRECTED HORSEPOWER 130 FF 14.8							
		RH	IAT	BHP					RH	IAT	BHP	BSPC		
		49	94	182	BSPC	0.525			36	102	178	BSPC	0.483	
		1.0343	1.0312	182	at 5.84 lbs p/gal				1.02	1.0196	178	at 5.84 lbs p/gal		
19.5°/2400 CORRECTED HORSEPOWER 142 FF 12							19.5°/2400 CORRECTED HORSEPOWER 142 FF 12.3							
		RH	IAT	BHP					RH	IAT	BHP	BSPC		
		45	98	133	BSPC	0.527			38	103	134	BSPC	0.535	
		1.0315	1.034	133	at 5.84 lbs p/gal				1.02	1.0405	134	at 5.84 lbs p/gal		
	RH	RELATIVE HUMIDITY %								WOT 27.6/2700 CORRECTED HORSEPOWER 262				
	IAT	INLET AIR TEMPERATURE F								BARO				
	BHP	BRAKE HORSEPOWER								29.9				
	FF	FUEL FLOW GPH								1.0077				
									1.02					
									1.0377					
									247					

Dynamometer data. Brake hp is derived from measured torque and rpm, and is then corrected for standard-day conditions using chart factors for atmospheric pressure, humidity, and temperature.

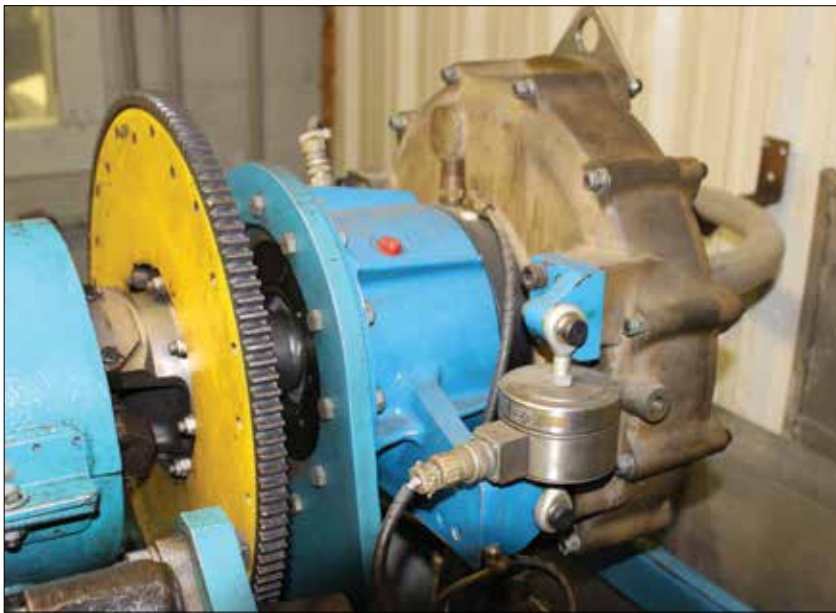
540 on the Barrett dynamometer with standard aircraft constant-flow injection and magnetos, then record power and economy runs, shut down, swap to the EFii systems, and run again...same engine, same dyno, same day. With thousands of hours of experience at the console, Monty would operate the dyno. I would attend as a representative of KITPLANES®, monitor the runs, and report the results for the magazine. It would be an old-fashioned “run what

you bring,” in the great gearhead tradition. As you might expect, everyone agreed immediately, and we all settled down to wait for the appointed day.

Tulsa, Late June

It's a beautiful, hot morning at KTUL. John Walker has arrived, with new in-laws Shayne and Phyllis McDaniel. I flew Monty Barrett into town from his home in Cookson, OK. Allen Barrett, as usual, was already at the shop when we got there, and had completed a final break-in and warm-up run. The Slick mags and Bendix RSA-10 components installed on Walker's engine for the test were nothing special, just used spares pulled from various shelves and boxes in the Barrett storerooms. Most of the break-in running had been done the previous day, after thrashing with a weak coil, an incorrect servo line hookup, and a bit of uneven distribution from the flow divider on the Bendix fuel injection.

Monty settled in his chair and fired up the 540. He let it run until he was satisfied with temperatures, then started a power run before abruptly shutting it all down and declaring a fouled plug. I can't say any of us had really noticed, but that's why we were happy to have Mr. Barrett running the dyno. Everyone jumped in and swapped all twelve for new Champions.



The heart of a conventional engine dynamometer...the water brake and load cell. Look for more about aircraft engine dynamometers and test stands in a future issue of KITPLANES®.



Monty Barrett at the console. Engine control on the operator's right, water brake and air controls on the left. Monty is scanning a bank of engine instruments, here off camera.

Barrett lit it off again. This time he was satisfied, and started into the run schedule. Paisley and I had previously agreed on five test points. We would start with wide open throttle and 2700 rpm, adjusting mixture for maximum dynamometer torque. Next

would be a reduction to 24 inches and 2700 to simulate WOT climb through roughly 5000 feet, again adjusting mixture for max torque, followed by the same at 19.5 inches/2700 to simulate 10,000 feet. The fourth and fifth tests were more subjective. We would

have Barrett set 24 inches/2400 and 19.5 inches/2400 to simulate cruise conditions, then search for the lowest possible fuel flow without significant torque loss...a low BSFC (Brake Specific Fuel Consumption, pounds of fuel per horsepower, per hour).

The five points went off without a hitch. Maximum *brake* horsepower (at 90° F inlet temperature) was 259, and the BSFC values were about where expected, around 0.52. Allen Barrett went off to compute the horsepower correction factors while everyone chattered, grinned, and waved their arms...gearheads in paradise! Allen came back with 276 *corrected* horsepower, which is what the engine would produce given standard-day temperature, humidity, and barometric pressure. That's realistic for a good plain vanilla 540, so out came the tools, and the old-school fuel and ignition gear went back onto the shelves. The mags came off by removing two clamps each, then disconnecting the plug wires, followed by removing the spark plugs. Working in

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the direction of fuel flow, stripping the fuel system meant removing the engine driven pump, the RSA-10 servo, the fuel divider, six stainless injector lines, and the individual fuel nozzles. It went quickly.

Paisley took about an hour for a tech presentation about EFii systems, including his Bus Manager product, a one-box device to simplify wiring redundant power sources for electrically-dependent

engines. Then the process of installing the EFii gear began. Allen Barrett and Paisley thrashed steadily, with help here and there from Walker, myself, and the McDaniel clan. The intake manifold got a slightly modified 80-mm BBK throttle body. The spark plug holes got brass thread adapters and new NGK Iridium plugs. Silicone plug leads were assembled using suppression core wire

and silicone boots. Subaru coils were mounted on machined plates, which did double duty as block-offs for the magneto openings in the accessory case. The system is crank-triggered, using Hall effect sensors on a case mount, and three small magnets inserted into the flywheel. The ignition system was completed by routing the Hall sensor wiring to the Simple Digital Systems

Mechanical or Electronic?

An engineer could easily argue that the first engine to take flight was fuel injected. For sure, the Wright Flyer's 12-hp four-cylinder had nothing like a carburetor. Gravity supplied fuel pressure, which was regulated with a valve, and the fuel dripped directly into the intake manifold. At the fundamental level we do the same with fuel injection today, using more pressure and far more control.

Constant Flow

Mechanical constant-flow injection is the general aviation standard. The Bendix-style system (Fig.1) is quite simple. A pump draws fuel from a tank and supplies it to the inlet of a fuel metering device known as a fuel servo. The servo is really a regulator, varying fuel flow in response to engine intake air velocity. There are no sensors or electronics; regulation is done with air and fuel diaphragms connected to a fuel metering ball valve.

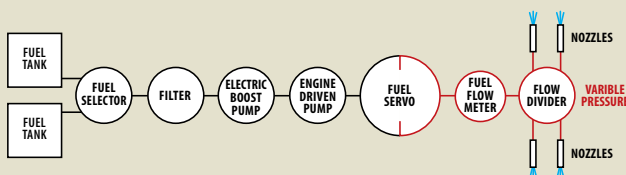


Fig. 1: Generic Bendix-type aircraft constant-flow fuel system.

The variable outlet flow is piped to a flow divider on top of the engine, then onward to the individual fuel nozzles screwed into each cylinder head. The nozzles are often called injectors, but that label suggests more complexity than they deserve. At the basic level, each nozzle is little more than a carefully calibrated orifice, with an air bleed to improve atomization at idle. Fuel flows through all the nozzles, all the time, with quantity determined by the fuel servo.

That nozzle pressure can be very low. For example, consider Fig. 2, a Lycoming chart for the angle-valve four-cylinder models. An economy fuel flow of six gph (36 pounds per hour) is only a bit over one psig. It's even less at idle. Nozzle pressures rise to significant levels only at higher power settings. For example, an IO-390 at full power would require 18 to 18.5 gph, or about 110 pounds per hour; nozzle pressure would be 9.5 psig. Note that a three-fold quantity increase required a nine-fold pressure increase, a function of the fixed nozzle orifice.

Electronic PWM Injection

There was a time when rare, really high performance cars used constant-flow injection. In those days a fuel-injected car was

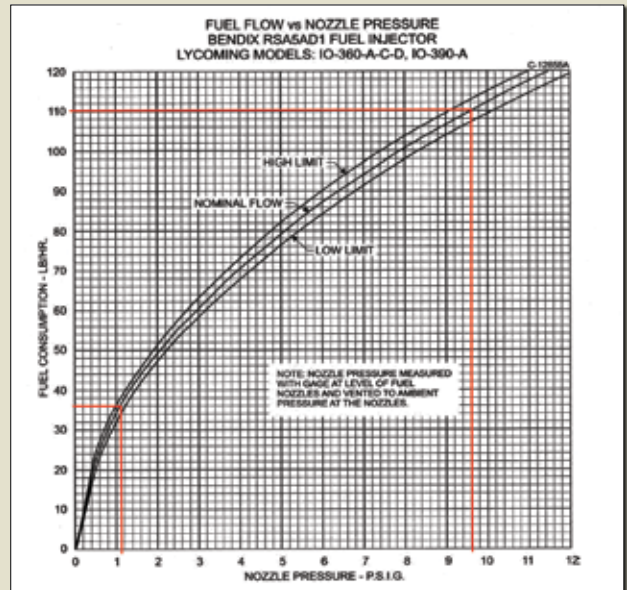


Fig. 2: Fuel flow vs. nozzle pressure, constant-flow system.

something special. Today most cars are equipped with pulse width modulated electronic injection, not for power, but rather because of its accuracy.

The key component is the electromagnetic fuel injector (Fig. 3). Although highly engineered and manufactured to extremely close tolerances, they're quite simple in principle. The only moving part is a pin with a pointed tip. A spring pushes the tip of the pin into a shaped nozzle in the business end of the injector, forming a closed valve. An electromagnet in the middle of the injector body surrounds the pin. When energized, the magnet lifts the pin a tiny distance so its tip no longer blocks the valve orifice, and fuel supplied to the top of the injector flows through the body and squirts from the open valve. The injector is either fully open, fully closed, or for a tiny fraction of a second, in transit between the two.



Fig. 3: Siemens short-body 60 lbs/hr injector. (Siemens Deka photo)

Many cars (and Protek's EFii system) use multi-point injection, i.e., an individual injector for each cylinder. The injectors are connected together with hose or pipe sections. An electric pump (or dual pumps) supplies fuel to the injector string, with high pressure at the injectors carefully stabilized at a single set value by a manifold-pressure-compensated

ECU, which in this case, Paisley simply strapped to the dynamometer frame. In the airplane, the SDS ECU would be mounted in the cabin.

Some months prior, Allen Barrett had sent the Lycoming intake tubes and flywheel to Paisley's facility at Cable Airport in Upland, California. Protek installed the flywheel trigger magnets in the proper loca-

tions, and welded a threaded spigot on each intake tube to mount the Siemens fuel injectors. On dyno day, all that remained was to daisy-chain the injectors together with pre-made fire-sleeved flex hoses to form the pressurized fuel rail. The fuel supply was routed from the dyno room's 100LL tank through, in turn, the dyno's fuel flow meter, a 90-micron pre-filter, the

dual Walbro electric fuel pump module, a 10-micron fine filter, and finally to a connection at the inlet end of the fuel rail. An adjustable Aeromotive pressure regulator was connected to the outlet end. In an aircraft installation, fuel is then returned to the tank through a second fuel flow meter, and a duplex fuel valve in the case of low-wing tanks. The Barrett dyno room

adjustable regulator (Fig.4). The system pumps far more fuel (about 40 gph for the EFii) past the injectors than they need to feed the engine; the excess fuel exits the regulator and is returned to the aircraft tanks.

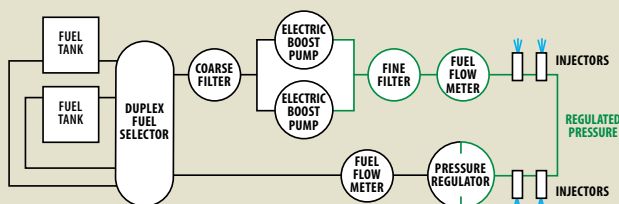


Fig. 4: Generic aircraft electronic injection fuel flow.

The injectors are carefully calibrated to deliver a labeled flow quantity when open. Given a known flow rate at a known pressure, a specific quantity of fuel can be injected *by calculating the length of time to hold each injector open*. That's the primary task of the ECU (electronic control unit). It connects and disconnects the electromagnet power in a constant "on-off-on" pattern, continuously calculating the required fuel and changing the relative "on" and "off" time periods. A graph of the calculated times might look like Fig. 5, thus the label "pulse width modulation."

Which is Better?

The key operating differences are a function of fuel pressure at the injection point. As noted, constant-flow systems are operating with no significant nozzle pressure when the engine is at low power. The limited pressure has two effects. First, fuel boils easily in the injector lines. When it does, fuel arrives at each nozzle as a random mix of liquid and vapor. Second, the fixed orifice nozzles can't proportion the flow; getting equal amounts of fuel to all cylinders becomes a function of the flow divider's spool and spring. The result can be imperfect fuel distribution, both between cylinders and within each combustion chamber.

The EFI injector *always* has high pressure at the nozzle. The ProTek EFii, for example, is set at 35 psi. Returning to Fig.2, that is 35 times higher than the mechanical system's pressure at a six-gph economy cruise flow. At idle the difference is even greater. The injector-open time can be shortened for a small flow quantity, but each squirt remains consistent and well atomized. You can expect the EFI system to be smoother at idle and partial power.

In the case of a constant speed, low RPM engine, the EFI advantage disappears at full throttle. The CF system is now operating at a reasonable pressure. Relative nozzle size dominates distribution between cylinders, and there is no boiling. Both PWM and CF systems deliver

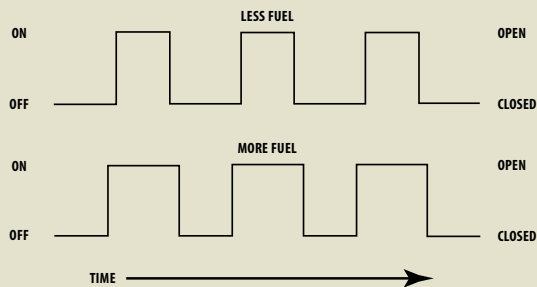


Fig. 5: Pulse width modulation.

fuel while the intake valve is closed, so solid stream or spray doesn't matter very much; at high volumes much of the fuel merely wets the port walls. With either system, actual vaporization begins with the addition of heat, and is completed by the violent air velocity and pressure change when the intake valve is opened.

One obvious point in favor of conventional injection is independence from electrical power. An EFI system is entirely dependent on a steady supply of electrons, and is generally installed with provision for backup power. . . usually dual batteries, often dual alternators, and perhaps a dual ECU.

Speaking of electrical power, let's take a moment and look at electronic ignition. There are endless claims out there regarding power gains due to "hotter spark," most of which have no basis in reality. The ideal stoichiometric fuel-air mixture is *easy* to light. Almost any practical ignition will get the job done, including magnetos. Lit is lit.

El truly does shine in many areas not related to maximum power. Wide spark plug gaps, long spark duration, multiple sparks, and increased electrical energy make it possible to reliably light mixtures which are *not* ideal, notably very rich and very lean. El's tend to demonstrate greater spark timing accuracy, and as most are distributorless, they can't crossfire at altitude. Perhaps best of all, they develop full spark energy at very low cranking rpm, even near zero, as their power source is external and constant, rather than proportional to rpm.

So which is better? It depends on what you value most. EFI offers efficiency and convenience in return for greater cost and complexity, while mechanical injection is stone simple, reliable, and offers equal power. It may yet be a while before GA turns its back on constant flow. Electronic ignition, however, seems to be gaining critical mass in the marketplace. The number one reason seems to be easy starting, closely followed by cruise fuel savings.

This might be a fine time to sell the Ace Magneto Co. stock you inherited from good ole Uncle Bob.

—D.H.



Robert Paisley wiring and plumbing EFii components. SDS ECU (gold box) and fuel pump module are simply strapped to the dyno frame. Looks messy, but it's strictly temporary.



Left side fuel rail assembly. Individual Siemens injectors squirt into the Lycoming intake pipes via welded ports. Hoses link injectors so they all share a common supply at a fixed pressure.

had an available return line, but did not have a second fuel flow meter, so Paisley elected to tee the fuel return back into the supply line at the pump inlet in order to provide an accurate consumption rate and BSFC computation.

More than six hot hours after shutdown, we were again ready to run. The SDS ECU has two operator controls (both usually panel mounted), a pushbutton programming interface, and a rich-lean rotary trim knob. Paisley positioned the trim knob on the dyno console, where it would take the place of a conventional mixture control knob. Monty Barrett tried to light it off, but there was no joy. The dyno's king-size starter motor was pulling battery voltage quite low, causing the ECU to reset. Allen Barrett jumped in his truck and retrieved an additional battery from the local auto parts store, then hot-wired it to the ECU, independent of the start battery. This time the 540 fired up when Barrett hit the button. He warmed it, then raised the rpm. After a moment playing with the mixture knob and staring at the gauges, he declared it did not have enough fuel flow and shut it down again. Paisley grinned, said "No problem," picked up the programmer, and changed the available injector flow range by punching a few keys...a nice trick. Let the fun begin!

Eyebrows went up on the restart... it turned over twice and idled like a clock. Barrett ran through the agreed five data points without much apparent effort, twisting the mixture trim knob as required while balancing the increasing torque with the Kahn's pump control to maintain the desired rpm. The full-power numbers were low (see

the chart), but the 2400 rpm "lowest BSFC" was quite good...the cruise fuel economy advantage most of us have learned to expect with electronic ignition. Nobody paid much attention to the 19.5-inch/2400 BSFC value, as we were all more interested in the missing power.

I asked Paisley what he wanted to change. He said all it needed was about



The EFii system uses a slightly modified 80mm BBK-brand throttle body for air control. The air temperature sensor connectors (two for a dual ECU system) are facing the camera. The throttle position sensor is on top. No mixture control; that's electronic.

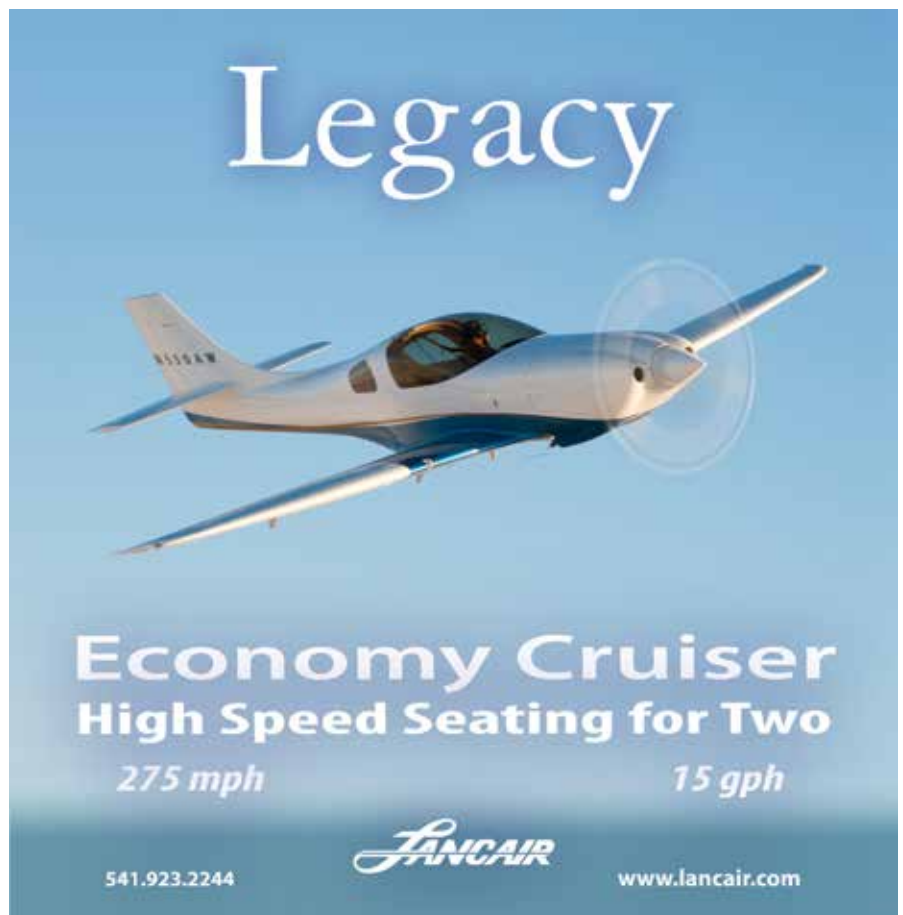
two less degrees of spark advance, but he had a plane to catch; John Walker could make the change (another pushbutton job), and we could run again. Allen Barrett and I spent about 20 minutes arranging an unrelated experiment to run at the same time Walker made the timing change, and at 4:47 p.m. on a long day, it was time for one more run. Again, it lit off like a car when Barrett pushed the button, and eight minutes later we were done. The timing change *lost* three hp.

Just about then, Paisley returned from the airline terminal; his plane had been delayed. We were all too tired to rib him about the horsepower. It was a hoot, but enough was enough. As they say back home, sometimes you can get too much candy for a nickel.

Postscript

Allen Barrett was back at the shop at 7a.m. Walker and the McDaniels were there when I came straggling in from Cookson. By late morning the 540 was stripped, pickled, and foamed into a shipping box.

Phones beeped and chirped with a group email from Paisley, who'd been thinking about the results. He felt it had been a mistake to plumb the fuel rail return back to the pump inlet. The hot fuel, upon release from the pressure regulator, may have generated vapor bubbles due to the pressure drop, and those bubbles may have re-circulated into the fuel rail, upsetting fuel distribution. It wasn't unreasonable. No one could say for sure if the bubbles had been there, or if they would have collapsed when returned to 35 psi in the rail. All telemetry readings were stable, so perhaps it made no difference at all... and with the engine in a box, it really didn't matter. At least he had a theory. Old gearheads know how things can go. They've brought home trophies, and they've hauled home wrecks, and often they didn't know why it turned out either way. All we can say for sure is that we gave both systems a fair shot. On this one particular day in June, the old-school stuff twisted the Kahn pump a little harder. ✚



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