PROPULSION / ELECTRIC
WHERE DO WE GO FROM HERE?

BATTERY

Our editors explore the future of general aviation propulsion technologies

Many scoff at the notion of electrically powered aircraft. After all, what do you do when the batteries run out?

Short-sighted, I say. Already, battery-powered, light two-place airplanes have the potential to fly for three hours or more, which would satisfy the aviation fix for many pilots. Such airplanes aren't quite ready for prime time, but soon they will be.

More practical applications for electric propulsion may include a hybrid approach that uses on-board generators to drive electric motors that drive propellers. Such generators might even be internal-combustion engines or perhaps fuel cells in the future.

Regardless, most futurists believe we are entering an all-electric age, where internal-combustion engines will be phased out in favor of more efficient and simpler electric motors. Aviation is unlikely to be an exception to that movement over the long term.

We explore the short- and long-term possibilities in this third and final part of our series on the future of propulsion. Share your feedback via comments on our Reporting Points blog and our Facebook page.

—TOM HAINES, EDITOR IN CHIEF

POWER

EXPLORING THE FUTURE OF GENERAL AVIATION PROPULSION (THIRD OF THREE PARTS)

THE eSPYDER'S carbon-fiber propeller is custom designed by Helix Carbon GmbH of Germany. Prop diameter is 70 inches.

THE eSPYDER is powered by a Yuneec Power Drive brushless motor of 24 KW (32 horsepower).

PROPULSION / ELECTRIC
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PIPISTREL Taurus G4.

ELECTRIC INSTEAD

Toward a fossil-free future

BY THOMAS A. HORNE

DESIGNED AND TESTED by Yuneec International, the model e430 (above) is now being sold and supported by GreenWing International in the United States. It made its debut at the 2010 EAA AirVenture and is one of the more appealing electric two-seaters on the market. With a battery endurance of three hours and a cruise speed of 52 knots, the e430 could make a great training airplane.

T**HERE COME TIMES IN THE HISTORY OF TECHNOLOGY** when critical variables merge, making revolutionary advances imperative. We're at one of those points now, with two huge developments radically affecting the future of general aviation.

One is the escalating price of fossil fuels. While a gallon of avgas cost a mere 75 cents or so back in the mid-1970s, it has skyrocketed in many areas to the $6-per-gallon mark—enough to cause hordes of pilots to drop out of flying and, perhaps more significantly, to deter a younger generation of potential pilots from ever signing up for lessons in the first place. Worse, there's no sign of this changing. The price of oil is now forever linked to the whims and calculus of politics in the Middle East. Drilling and mining for new, domestic oil sources is expensive enough to blunt any potential savings at the pump. Plus, it's also politically fraught.

To this, add environmental concerns. Taxes on carbon emissions already are facts of life in European aviation. Under emissions trading schemes, operators of airliners, business jets, and turboprops alike must buy credits designed to offset the environmental damage their aircraft create. What began with the development of "low-lead" avgas has already kicked off a trend toward research in biofuels, an increased awareness of the cleaner combustion possible with the use of modern diesel-engine technology, and an awakening interest in the first steps toward developing solar-powered airplanes.

Noise is another escalating environmental burr under general aviation's saddle. General aviation operations in Europe—especially Germany and Switzerland—are already hindered by noise curfews, mandatory exhaust silencers, outright bans, and heavy fines for the noncompliant. Talk about user fees!

Fossil-fuel curtailment pressures are coming both from the top and bottom of the civil aviation spectrum. Fuel jumped from 20 percent of the cost of airline operations a mere 10 years ago to 50 percent today. Meanwhile, the government, always on the hunt for more revenue, sees easy pickings.

"Our short-term goal is to sell 10 e430s and 50 eSpyders in the American market in 2013."

—TIAN YU, PRESIDENT, YUNEEC INTERNATIONAL

ILLUSTRATION BY KYLE HILTON

ELECTRICITY TO THE RESCUE

If you're trying to eliminate avgas/diesel costs, fly without polluting, or aviate silently, then electrical propulsion fills the bill. Right now, general aviation's electric engines are still in the research and development phase, with most of the engines putting out between 20 and 30 horsepower. The motors are very small and light, and have just two moving parts, making "overhauls" simple. As with many other initiatives in the growing Light Sport Aircraft industry, electrical propulsion has been a creature of China and Eastern Europe, with manufacturers Yuneec International (Shanghai, China) and Pipistrel (Slovenia) leading the pack.

Several lines of electrically powered and augmented aircraft have been

FLYING ELECTRIC

Noteworthy developments

BY THOMAS A. HORNE

HERE ARE A FEW pioneering electrically powered designs, all of them powered by lithium polymer batteries. To date, only two are reportedly available for purchase in the United States: the Green Wing eSpyder and the Green Wing e430.

GREENWING E340—Originally developed by Yuneec International. Powered by a 54-hp Yuneec motor, this airplane has an 84-lb battery, an empty weight of 561 lbs (which includes the battery), and a max takeoff weight of 946 lbs. Charge times run three to four hours, flying endurance runs about three hours. Price has yet to be announced.

PC AERO ELEKTRA ONE—A single-seat, retractable German design with a 21-hp Geiger Engineering motor, a claimed cruise speed of 87 kts, a charge time of three to four hours, and an endurance of four hours. Battery weight is 220 lbs, empty weight is 440 lbs, and max takeoff weight is 660 lbs. Price has been set at $80,000.

GREEN WING eSPYDER—Based on the Flightstar design, the eSpyder was developed by Yuneec and is available as an Experimental category kitplane. Powered by a Yuneec 32-hp motor, it can cruise between 26 and 39 kts, its charge time is 2.5 hours, and flying time is 40 to 50 minutes. Battery weight is 76 lbs, and max takeoff weight is 550 lbs. Price $35,000.

PIPISTREL TAURUS ELECTRO—Its 50-hp retractable motor is meant for use during takeoff and climb. At altitude, the engine is stowed and the airplane can fly as a sailplane. With a max takeoff weight of 1,210 lbs, it can cruise as fast as 160 kts. Battery weight is 24 lbs, charge time is seven hours, and endurance eight hours, 35 minutes. Price $89,500.

PIPISTREL G4—This four-seater won the $1.35 million 2012 NASA Green Flight Challenge prize. With a KOKAM battery weighing 1,100 lbs, endurance is 2.45 hours and cruise speeds range from 87 to 100 kts. It's powered by a 200-hp Pipistrel motor and has a max takeoff weight of 3,300 lbs. Price N/A.

flying since the mid-2000s, but a sighting would be rare in the United States. Most have been on display in Europe, with the biggest showcase being Germany's AERO Friedrichshafen exhibition.

However, Yuneec and Pipistrel have made showings at EAA's annual AirVenture at Oshkosh. At this year's AirVenture, GreenWing International's eSpyder—an Experimental-category, amateur-built ultralight—was scheduled to be showcased. GreenWing International was formed by Yuneec to produce, sell, and support the eSpyder and a two-seat design, the e430.

UPS AND DOWNS

But if electrical motors are lightweight, reliable, and stone-simple, the same can't be said for the batteries that power them. And here we come to the central issue affecting any future advances in the performance and utility of electrically powered aircraft.

The lithium-ion and lithium polymer batteries used in these aircraft have benefitted from a number of improvements in recent years. Most of them have come from the burgeoning cellphone, consumer electronics, and electric/hybrid automotive applications. Why lithium batteries? Mainly because they are comparatively light when compared to the batteries we are most familiar with, have very low self-discharge rates, and require no maintenance.

For example, the lead-acid battery in your car is not only heavy, it also can self-discharge 20 percent of its capacity per month, is subject to eventual failure from lead sulfate deposits, and its electrolyte is highly corrosive. Lithium-ion batteries use a gel electrolyte; lithium polymer batteries have layers of polymerized composite material that hold a lithium-salt electrolyte, plus a polymer-laminate case that can be shaped.

In terms of energy density (the amount of energy produced per unit of weight), lead-acid batteries put out about 11 watts per pound. This gives them enough power for short bursts at high output—perfect for starting your car engine. But not for

SOLAR-ELECTRIC HYBRIDOLOGY

BATTERY-POWERED ELECTRIC PROPULSION MAY BE THE FIRST ECO-FRIENDLY technology to make it to market, but there's another means of driving electric motors—and it's been around longer. Solar-powered electric motors have been powering light aircraft for years. Under this scheme, solar cells mounted on the upper wing surfaces collect energy.

Most recently, the *Solar Impulse* has been getting all the attention as it crossed the United States. This technology demonstrator has made a huge step forward in that its batteries have proven to last throughout the night. Plans are for its successor to fly around the world in 2015, with one stop on each continent.

But way back in 1981, famed aeronautical engineer Paul MacCready and his team at AeroVironment, Inc. created the *Solar Challenger*, an airplane capable of flying several hours and hundreds of miles on the power of its solar cells. The *Solar Challenger* even crossed the English Channel.

In 1990, designer Eric Raymond flew his *Sunseeker* solar-powered motorglider across the United States in 21 stages and 121 flying hours. Raymond continues to fly his latest solar-electric *Sunseeker II* all over Europe. On one flight he took off from Friedrichshafen, Germany; crossed the Alps; flew to Sicily; and then to Slovenia. Raymond even helped to build *Solar Impulse*.

In 1996, a team from the University of Stuttgart in Germany flew its *Icaré II* to win Germany's Berblinger prize recognizing innovative designs featuring environmental sustainability.

In 2001, MacCready's AeroVironment built another solar-electric design, the *Helios*. The 230-foot-wingspan *Helios* was remote-controlled and set an altitude record of 90,000 feet. Two other electric drones, built in 2005 (by Alan Cocconi's AC Propulsion) and 2010 (by Anglo-American company QinetiQ), also have demonstrated impressive endurances.

While still in its infancy, solar power may yet augment future power systems based on today's battery-electric designs. *-TAH*

eSPYDER FLIGHT

Gas-free fun flying

BY THOMAS A. HORNE

VIDEO EXTRA
View a video of Tom Horne flying the eSpyder.

A FEW YEARS BACK, I FLEW QUITE A NUMBER OF ultralights as editor of AOPA's *Ultralight Pilot*. Some were dreadful, some flew very well, and all were *loud!* How loud? Imagine a two-stroke engine screaming away, just a foot or two from your head. The range in handling qualities among these airplanes was shocking. A thing called the Rotec Rally was a standout in this department. To put the right amount of tension on the propeller's belt drive, the engine's height was adjusted by adding to or subtracting from stacks of washers. The control-stick actuation was counterintuitive, to boot. To turn right, you moved the stick to the left. Egads.

Of the handful of ultralights I liked, the original Flightstar was one of the best. It was a single seater, powered by a 27-horsepower Rotax engine, and its controls and handling were pretty much conventional in every way. Flash forward to the South Woodstock Airport in northeast Connecticut, the home of a rejuvenated Flightstar. I'm in the cockpit of an eSpyder, an electrically powered derivative of the Flightstar, and listening to a preflight by Tom Peghiny—Flight Design USA's president, and the designer of both the original and electric versions of the Flightstar ultralight. In front of me is a 27-horsepower Yuneec electric motor sporting a 70-inch-diameter, three-blade carbon fiber propeller. The cockpit features gauges that show, yes, airspeed, but also battery temperature, power output, voltage, prop rpm, and motor temperature. There's a throttle by my left hand, and my seat is right above a 76-pound lithium polymer battery.

Starting the eSpyder is like flipping a light switch. Just advance the throttle and instantly the propeller leaps into action—almost noiselessly. There is no warm-up time, no magneto checks, no propeller cycling, no cylinders to crack, and—of course—no fuel selectors or pumps. Well, actually, there is fuel: it's the electricity stored in the battery. If the voltage gauge starts to head below 60, I'm told, make for the runway. The battery takes two to three hours to charge, and can run the ship for about 45 to 50 minutes if you go easy on the power.

I advance the throttle, the prop comes alive, and then I taxi into position. It takes me a few seconds to contemplate what's about to happen, and review the target speeds—rotate at 30 mph, climb at 45 mph, cruise at 40 mph, and approach at 45 mph. I give it full power, the propeller instantly spools up, and I'm accelerating very briskly toward that 30 mph. Aft pressure on the control stick, and I'm off the ground in what can't have been more than 100 feet, and climbing like mad.

At 500 feet agl I power back to 40 mph and gather my wits. It takes a short while to get accustomed to the light wing loading, control responses, and sensitivity to turbulence. There's also a certain sense of vulnerability that comes with flying in a cockpit that's open all around. Some liken the electric motor's noise to that of a washing machine in the spin cycle, but I think it sounds more like an electric lawn mower—a quiet one. The propeller makes a whooshing sound like an electric fan, and there's the wind noise. But after pulling back to 1,600 rpm and slowing to 35 mph, things become much quieter. Was that a car door slamming? Yes, you can hear things happen on the surface.

Some turbulence crops up as I fly over the airport, and the eSpyder reacted according to its ultralight roots. There was rolling and yawing, all of it easily corrected, but getting used to the adverse yaw created by the eSpyder's full-span ailerons takes some time. I flew my patterns like those you'd make flying a piston single, but I'm positive that closer-in patterns are just as easy and safe. After all, turn radius is pretty small when you're flying at 45 mph.

There's an audience on the ground, waiting to judge my landing technique. But an airplane is an airplane, so I lined up with the extended centerline, flew 45 down final, then closed the throttle at about one foot above the runway. When you close the throttle, the engine stops. *Right now.* With plenty of airspeed for a smooth flare, I touched down on the mains and rolled to a stop, deadstick.

Peghiny takes the eSpyder up and shows off its glide performance. He's up there with the engine stopped, breezing along and shouting down to our small group below.

Yuneec has formed a company to market the eSpyder, called GreenWing International. Now the airplane has dual lithium-ion batteries and, therefore, longer endurance. Last I heard, the retail price will be $35,000. Will the market welcome the eSpyder? For pilots wanting gas-free fun flying, the attraction will be powerful. Plus, the owner will have the added distinction of being an early adopter of a technology that's closer to mainstream than many might think. *—TAH* powering an airplane. To have the same amount of energy as a pound of gasoline (at 5,500 watts per pound, gasoline reigns in energy density), you'd need to carry about 500 pounds of lead-acid batteries! So lithium batteries it must be.

Still, they are heavy. The lithium polymer battery that powers the e430 weighs 184 pounds, but has a weight-to-power advantage over lead-acid batteries of about 1,400 percent. In the e430, the battery can last as long as three hours in flight, and requires one hour of charging time for each hour flown.

Other airplanes have similar endurance and recharge times, depending on how long you use higher power settings. Some electric airplanes stretch battery power by using it for takeoffs and initial climbs; after that, the engine is shut down and the airplane can be flown as a glider.

A DOWNSIDE

With all of their attributes, do lithium batteries have any disadvantages? Apart from short endurances and long recharge times, lithium batteries generate heat when they charge and discharge. Control units are needed to prevent overcharging, manage battery condition, and maintain balanced charges among the cells.

But this is a mild inconvenience when you consider that lithium is flammable if exposed to air. If there's leakage, or damage to the battery's protective case, the battery can catch fire. There have been lithium battery fires in hybrid automobiles. A Cessna Citation CJ4 had a lithium-ion battery fire while hooked up to a ground power unit; an emergency airworthiness directive was issued, and as a result Cessna gave all 42 CJ4s in the fleet replacement nickel-cadmium or lead-acid batteries.

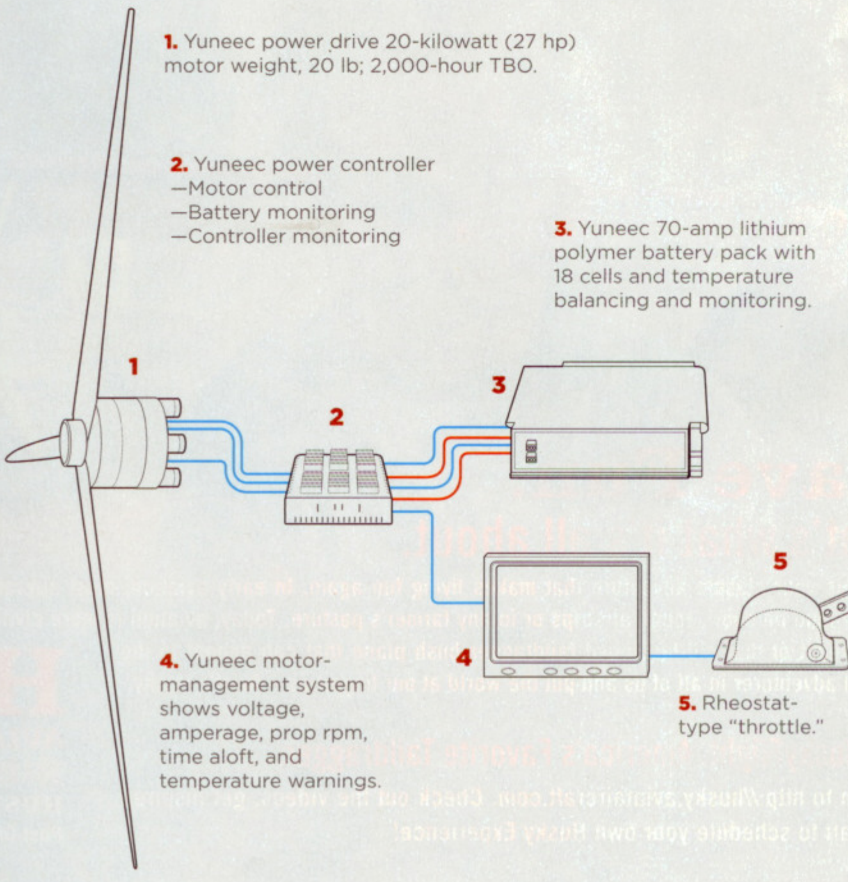
And then there were the lithium battery fires on Boeing's Dreamliners—one in flight, and one on the ground. Overcharging was suspected, but as yet there has been no determination of cause. The fires prompted a grounding of the entire fleet.

Advocates say that lithium batteries are safe if kept properly sealed and protected, monitored carefully, and

HOW IT WORKS

It's electric!

Yuneec International is by far the biggest player in the aircraft electric-propulsion game, but Pipistrel also produces its own power systems. Whatever the make, the propulsion systems share the same basic design objectives. First of all, the battery must have a protective case to prevent damage and keep lithium from coming into contact with air. It's also imperative to monitor the battery and motor for signs of abnormally high temperatures—and potential thermal runaways. Special circuitry keeps battery cell voltages in line, as well as charging and discharging rates. On the pilot's instrument panel, voltage is prominently displayed because voltage levels serve as measures of the "fuel" remaining.



1. Yuneec power drive 20-kilowatt (27 hp) motor weight, 20 lb; 2,000-hour TBO.

2. Yuneec power controller
—Motor control
—Battery monitoring
—Controller monitoring

3. Yuneec 70-amp lithium polymer battery pack with 18 cells and temperature balancing and monitoring.

4. Yuneec motor-management system shows voltage, amperage, prop rpm, time aloft, and temperature warnings.

5. Rheostat-type "throttle."

ILLUSTRATION: STEVE KARP

charged according to manufacturer recommendations.

GOING FOR MAINSTREAM

No doubt about it, there still are other issues that must be addressed before electric airplanes are accepted by aviation's traditionally conservative customer base. Yes, battery endurance and recharge times must be improved. At the same time, engine power must be increased so that payloads and ranges can support missions other than flight training and recreational use. But it's important to move slowly and deliberately. Yuneec International was developing a four-seater, the e1000, last year when a test pilot was killed after the airplane suffered an inflight structural failure.

> **"The 787 moves huge amounts of electricity through its batteries, using them more like capacitors; electric light aircraft, in contrast, use careful charging and discharging of their batteries."**
>
> —TOM PEGHINY, PRESIDENT OF FLIGHT DESIGN USA AND ASTM COMMITTEE MEMBER DESIGNER OF THE eSPYDER

Perhaps more vexing will be the establishment of an infrastructure to support these new aircraft. First, an electrical power distribution network is needed. The automotive industry has only just begun to see embryonic efforts at setting up charging stations, which are few and far between. It will be difficult to grow this movement without more charging stations, and without more investors.

Tesla Motors, Inc. realized that it needed other companies to have an interest in growing the electric car industry, so it will reportedly allow Mercedes' B-Class Electric Drive cars (coming in 2014) to use Tesla-operated charging stations. Similarly, Tesla—its Model S is known for its high-quality propulsion system (416 max horsepower; 0 to 60 mph in 4.2 seconds; 300-mile range)—has also helped with the Electric Drive's motors and batteries.

ILLUSTRATION BY KYLE HILTON

> **"There is no easy or practical way to reduce battery weight. You can take a smaller number of batteries on board, but this will also make your endurance that much less."**
>
> **–TINE TOMAZIC, CHIEF OF RESEARCH AND DEVELOPMENT, PIPISTREL AIRCRAFT**

Helping competitors may sound counterintuitive, but this kind of out-of-the-box thinking may be necessary to legitimize an infant industry and spur a healthy community of suppliers. There are signs of this in Europe, where solar-cell installations atop trailers and hangars are available to power charging stations.

Last but certainly not least, electric airplanes need the legitimacy that only certification can bring. Germany has provided a certification pathway by letting airplanes built by Pipistrel, GreenWing, and other manufacturers come under that country's ultralight regulations, which are recognized by dozens of other nations. But Federal Aviation Administration certification has yet to occur. The term "electric airplane" doesn't even appear in FAR Part 1, where categories of airplanes are defined. Industry experts are hopeful that soon an electrically adapted variant of the Light Sport Aircraft (LSA) standards established by the American Society for Testing and Materials (ASTM) will be incorporated into the Federal Aviation Regulations to allow electric propulsion systems to power airplanes under an amendment to Special Light-Sport Aircraft (SLSA) airworthiness rules.

Fixing electric propulsion's shortcomings isn't impossible; it's a technical challenge that can be overcome. Let's say that the power, weight, battery, and infrastructure issues are addressed, which is saying a lot. As a first step toward mainstream acceptance, what will it take for flying schools to swap their aging Cessnas and Pipers for electric two-seaters? Maybe $10-a-gallon avgas. **AOPA**

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ILLUSTRATION BY KYLE HILTON