Left to right, Jerry Hill, Sam Steele, Dave Coombs, Paul Tackabury, Jim Schulzman and John Walling . . . hard working helpers pose just after the first flight.

white structure as nothing too extraordinary.

As I look back, I wish that I had recorded many day to day impressions on paper instead of in my head, but who would have suspected a "seven year sentence" when this project began? While living at Edwards we had the opportunity to visit Mojave airport, the location of Rutan Aircraft Factory, many a weekend. Somehow the energy felt there as we watched the Ezes flying in and out charged the personal batteries and sustained work at an intense (and creative) level. I always noted Paul's distinct pleasure as he crawled around the newest homebuilts. He often looked at me with a promising smile, "Someday." Building away, hour by hour, day by day, YEAR BY YEAR (are there others out there?) — never even seeing what the projected plane looks like in the air — drains one's energy and requires great sacrifice and determination. There is nothing like a fly-in to make you want to dash home and pick up the sanding block!

During these early days of building, there were energetic discussions between Dick and Burt Rutan, Mike Melvill and Paul. Most of these discussions drifted by me, as I prowled around the Rutan Aircraft Factory workshop with great fascination. It was about this time, in the Spring of 1978, that Burt put some of his early ideas for the Long-EZ on the drawing board. Concurrently, the partly built fuselage in our garage developed growing pains. Paul and Dick Rutan have been swapping flying stories for more years than I care to admit, and Dick convinced Paul that he should *expand* his plan. So Paul, working from some rough copies of Burt's plans, set about turning his VariEze fuselage facsimile into a Long-EZ-T before the Long-EZ prototype had even been built.

About that time I remember a few lopsided discussions out at Mojave — lopsided because Paul's physical stature peaks at the bottom of Burt's sideburns! The subject of some of these discussions was the proposed changes or modifications Paul wanted to make. Most were not tested and Burt, therefore, did not always sanction Paul's ideas. "Test this yourself, Paul."

I always enjoyed eavesdropping during discussions of aerodynamics and structure. I do remember that behind Burt's twinkling eyes dwelled an "obsession" that has probably contributed to his great design success — "keep it light." I got the idea that a structure must be aerodynamically strong enough for safety and performance without adding unnecessary weight. More than once I heard the advice, "If safety and performance call for a part

The extended sides of the EZ-T provide a lot of extra room in the cockpit.

Pam Tackabury cleaning the belly after the first flight.

to be one inch thick, make it EXACTLY ONE INCH THICK!!"

Ultimately, the EZ-T is a combination of a VariEze, a Long-EZ and my husband's imagination. And it is "light."

Paul continued to work on the plane every weekend and after a time the 8 foot chunks of foam acquired some form and a fuselage took shape. As the weeks went by the structure grew wooden slats for seats and one could say that it certainly looked like something that might one day carry people. At Edwards Air Force Base, where we were surrounded by airplanes, and where people live, eat and breath to the beat of the sonic boom, Paul's project was clearly something that would fly. But this attitude changed when the future brought a move of 3,500 miles across the country to Montgomery, Alabama.

News of the move kept Paul busy day and night. The fuselage was the great concern. At this point it was still only a "part" and, therefore, could be moved by Mayflower, as the saying goes. But putting it in someone else's hands, no matter how gentle, could not be done without a great amount of anxiety. In the end, as we packed it in the moving van, the structure was regarded by the movers as a playhouse for our two young girls, who indeed loved to sit, crawl and sleep in it while Daddy worked. It wasn't only the children's fondness for their playhouse that caused Paul to holler "TAKE GOOD CARE OF IT" one last time as the moving truck rolled down the drive on its way to Alabama.

Thus, in 1980, the EZ-T logged its first 3,500 miles, on a course that zigzagged across the country from Edwards, CA to Montgomery, AL. And it WAS a safe journey.

In Alabama, there were luscious trees, flowers, catfish — and NO sonic booms. People put CARS in their garages instead of airplanes and suddenly the EZ-T became a curiosity. The garage, by the way, was a great personal concern of mine. I had rented a "mail order" house on the telephone, all the way from California (in hindsight, it's hard for ME to believe I did that!). The house I'd rented sight unseen was supposed to have a "garage", but from the looks of some of the things I'd seen on the way into town, I was worried. I was greatly relieved to find that the garage was both large AND completely finished!

From the moment the moving van unloaded at our door, we aroused great interest on our little Montgomery street. As Paul's progress continued on the fuselage and beyond, many neighbors quietly observed his work. Most **wondered** what it was; but a few couldn't take the suspense. One day a neighbor, who'd been living on our street for many, many years, shuffled by with his dog, Barney. Paul was working in the garage as was true 90% of the time. Barney stopped, and Old Jim (as we later learned) stopped. Barney stared and Old Jim stared.

"Morning," said Paul.

"Mmm," answered Old Jim. And he and Barney walked on.

For several weeks the pair shuffled by. Then one day they stopped for a long time. Barney stared. And Old Jim stared.

"Morning," greeted Paul.

"This an aeroplane you're building?" Jim asked.

"Yep, sure is," answered Paul. And Jim and Barney shuffled on.

The next day they came along again. Jim stopped, and Barney stopped. Jim stared, and Barney stared.

"You fixin' to build this all yerself?" asked Jim.

"Yep, sure am," answered Paul as Jim and Barney shuffled off again.

But the next day Barney and his buddy were back. Jim stared. And Barney stared.

"Morning," said Paul.

"Mmm," replied Jim. Several minutes passed. Then Old Jim looked Paul straight in the eye and said, "You ain't really gonna fly this thing, are ya?"

Jenny, Molly and Mom learn all about wet sanding . . . at night, yet!

"Yep, someday," was Paul's laughing reply.

Jim and Barney shuffled away, Jim shaking his head and Barney wagging his tail.

I should write Old Jim a letter and tell him that Paul really did!

In Alabama the problems of the hot dry desert had been exchanged for those of a cooler, wet climate. The humidity never ceased to be a problem when working with fiberglass. In California one couldn't work quickly enough, in Alabama one was always waiting. If the plans said a job took 6 hours, you could count on a week. (Mind you, that is from the standpoint of an observer, not a worker.)

One new challenge we had in the South was keeping the garage warm during an unseasonbly cold winter. Paul had a plan. "Let's drill holes through the garage wall into the house and pump the warm inside air out." It may have been a good idea, however, the landlord squashed that one. Gas and electric heaters finally brought the temperature up and our bank account down. But Paul did manage to move ahead that winter. With gear and nosewheel installed, it appeared we had a large BUG growing in our garage.

After three years of observing the careful construction of the EZ-T, I thought it might be time to learn something about flying myself. I've heard "there I was at 3000 feet" stories for years, and I hoped that, perhaps, some of this aural onslaught might make my task easier. I was wrong. Learning to fly was the greatest challenge of my life, but I felt I had to stick with it. I had personally observed the hours and hours of work invested in our airplane, yet I frequently landed on the nosewheel. I knew that I'd better perfect my landings before the EZ-T was completed . . . or end my marriage! After nine months of hard labor, I finally produced a reasonable landing and earned my private pilot's license. However, the EZ-T was nearing yet another move.

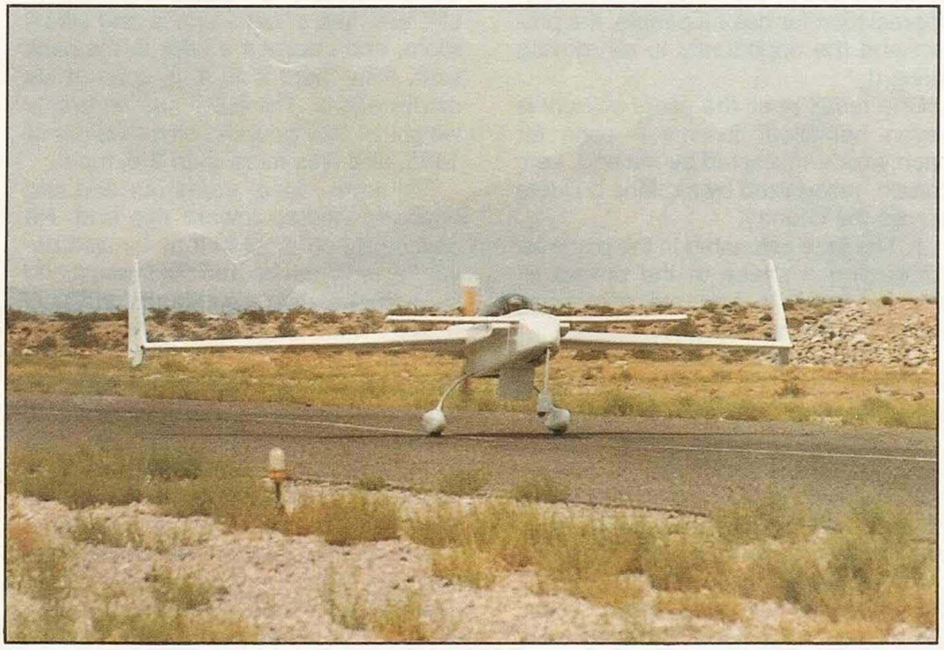
The EZ-T as it made its way across the U.S. from Alabama to Nevada.

Soon the white cold winter became a moist green summer, but before I could wipe the sweat from my brow, it was time to pre-flight and prepare for another cross-country move. This time the airplane HAD to travel in a place of importance. Paul built a special trailer for the second car, a little Honda, which we towed behind our station wagon. He then adapted the whole thing to piggyback the EZ-T.

This effort can scarcely be described. Our big Bug was to be vulnerable, perched above us as we rolled along — exposed to wind, rain and reckless drivers. Before we left Alabama, Paul called all the women together. "Okay, today we are going to have a garbage bag brigade." We nodded and smiled and wrapped the fuselage with nearly 100 plastic bags in order to give it some protection against possible calamities ahead. As we rolled down our driveway, with two kids, the dog and the EZ-T, we were a novel sight.

Everytime we stopped on this cross-country we encountered questioning people — "If you don't mind our asking . . . what is THAT?" In spite of the hailstorm and 40 mph winds in Mississippi, zig-zagging between friends and relatives, and adding an extra thousand miles because we could never BACK UP, we made it back, this time to the Nevada desert. It was 1981; we were all hot but the only pregnant member was the airplane which was ready to reproduce or finish itself by this time. Indeed, it was in the 100 degree desert heat, in a garage that was 127 degrees, that the wings were completed, the engine mounted, the systems installed, the finishing-finishing-finishing accomplished and the dream fulfilled.

Of course, there was the month when I couldn't use my washer and dryer located in my garage while Paul worked on fitting wings that stretched 30 feet corner to corner. And there was the time the winch, secured to the rafters so that Paul and I could turn the airplane over by ourselves, slipped — a little. There was also the thin layer of finishing dust, a fine gray primer that blanketed our existance aging everything it touched, especially me. There was the fiberglass that is still stuck to my kitchen



Touchdown on the first landing of the EZ-T — in 117° weather at Las Vegas.


Paul Tackabury and his EZ-T.

sink. There were new curious neighbors and the same old question, "Are you REALLY gonna fly this thing?" became redundant.

Finally, with the arrival of summer in 1985, there was also another move impending — this time back across the country to Washington, DC.

Paul decided that the EZ-T was NOT going to log another 3,000 miles rolling cross country; the final "push" was on. After seven years of meticulous construction, it would be unjust to shortcut the finishing, but the departure date was three months away. In the end it was the neighbors and friends who saved us. The final movement to painting involved lots of dust and grit — you might call it "true grit." It was the friends who helped us when we all — Jenny, Molly, Pam and Paul — sanded and sanded until our arms ached with fatigue. The only bright moment for me was the wet sanding. If you've never wet-sanded on a sizzling desert afternoon, temperature soaring to 117 degrees, the water dripping off you and the airplane — you just haven't lived!

At last, too slowly and too soon, the day of the first flight arrived. People gathered at the airport; when you've been building for nearly a decade, many people become interested. Even the good friend who had sold Paul the engine, Vern Dallman — a fellow homebuilder and aircraft aficionado — flew in from Lake Tahoe with an airplane full of guests.

We rolled the EZ-T out and the moment arrived. Vern had asked for the honor of pulling the prop for the first flight. After several tries, as people looked on in horror, the prop caught Vern's hand and the joy of the moment evaporated like tears on the hot pavement. Paul rushed Vern to the hospital and I rushed to clear the area, secure the airplane and encourage optimism for Vern. In the end, the accident brought 10 stitches and great disappointment. Our friend was able to fly his group back home that night, but the prop was split clear through. To this day I look at that splintered propeller with a wonder and a gladness that Vern's hand didn't encounter the same fate. He is one tough fella! But we all gained a cautious reminder that day.

That evening was the lowest point in the seven years progress of the EZ-T. Paul sadly reflected on the project, the help of friends and what seemed to be a full stop — a dead end. The airplane now had no prop and there was only one week before the move. The propeller had been carved by Ted Hendrickson of Snohomish, WA, to exact specifications; it had taken six months.

The somber mood continued the following Sunday morning. I rose early and decided to call Ted in Snohomish. He viewed our situation with interest, and, to our surprise and delight, he had made another prop with Paul's specifications — and kept it. He agreed to send it express, and before that Sunday was over we were trying to find new prop bolts and had a goal again in sight.

The next week was even busier. EVERYTHING is NEVER done. But underneath the activity was a calm, clear directed purpose. As is the result of many setbacks in life, we now had a greater appreciation for helpful people, the project and the opportunity to be moving forward.

One result of all the years of work is seven homebuilt axioms — one for each year — collected by me and, I am certain, recognized by airplane builders across the country.

1. The time estimated in the plans for completing a phase of the project — any phase — is accurate only when divided by 2 and multiplied by 10.

2. The quality control of your homebuilt airplane probably exceeds that of any other airplane you'll ever fly.

3. Airplane builders know how to think. I'm talking about real thinking — sitting quietly, staring into space, while working out plans and problems in one's head. Airplane builders do this!

4. You cannot really get fiberglass off the porcelain sink with Ajax, Comet, Clorox, your fingernails or a sharp knife. You can remove the blood you shed from attempted scrapings with a sharp knife, however.

5. An airplane builder never keeps a car in his garage, which is really a six letter word for "airplane workshop."

6. An old German saying passed down through my grandmother: Difficulties make life sweeter.

7. Anticipation is **not always** greater than fulfillment.

I have learned something more. The dedication of an airplane builder puts him or her into rarified air (not only literally). Few realize the length and breadth of this pursuit, especially when one does it alone. In this modern age we've become accustomed to "instant" everything — from instant grass and mashed potatoes to instant replay and Las Vegas marriages. Building an airplane means keeping at a task for a long period, having a goal and WORKING towards it, slowly (sometimes slower than others!) but without sacrificing perfection. I think this sort of action deserves a worthy nod. In fact, it reminds me of stories shared when I was a little girl about the men and women who built this country. In the 1980s it is common to talk of the heroes of the air who have the Right Stuff; one who builds his own flying machine has the "right stuff" to, and there is a powerful force behind this achievement.

On July 14, 1985, the project that began the same year my seven year old daughter was born, came to fruition. With over 7,000 miles of ground time back and forth across the United States, the EZ-T finally lifted into the skies for its first aeronautical mile. The airplane is a distinct combination of Ezes with a Lycoming O-320 160 hp engine and the wooden prop that was made by Ted Hendrickson. The cockpit is comfortable, with lots of extra space and elbow room; and I earned a stick in the back seat. Paul "kept it light" in spite of his modifications. The EZ-T has an empty weight of 825 pounds, gross weight of 1425, and flies more than 205 mph.

For seven "long" years our dad and husband worked toward this end. He accomplished most of it by himself because, although he had our interest and support, he didn't get much physical help from the family until the end when the going got rough and the ladies got going. He worked in starts and snatches while supporting us with a fulltime job, yet never sacrificed his best effort, right to the exhausting finale. Perhaps Paul might be an example to all those who are dying to try but fear it can't be done. It can. As Paul opened the canopy after that first flight, he was a radiant blur. "You did it," I cried, "**Someday** is here at last." For his inspiring effort, I salute my husband and his EZ-T.

A Piece of History

BY JOHN McAVOY
EAA CHAPTER 62

We receive many accounts of Young Eagle activities each day. Many, like the following story demonstrate how a Young Eagles event can turn out to be something special for pilots, volunteers and participants alike.

EAA Chapter 62 held a large Young Eagles event at Moffett Field in California during the 1998 International Young Eagles day. More than 50 aircraft participated in the rally.

The Flightline staging area where Young Eagles are registered before their flight. Note the "World's Largest Flag" on the left. More than 5,000 volunteers helped unfurl the flag in an event sponsored by a local radio station.

When you hear the name San Francisco, you probably envision cable cars, rolling hills and the Golden Gate Bridge. The San Francisco Bay Area encompasses over 3000 square miles and has a population of 20 million in 30 cities, including San Jose and Oakland.

At the southern end of San Francisco Bay lies the historic Moffett Field. Moffett's 70 years of diverse history include the honor of being the homeport for the U.S. Navies Dirgibles, most notably the Macon and the Akron. The massive hangar that used to house these giant, lighter-than-air ships is now a national monument and serves as an icon to the south end of the area and Silicon Valley.

NASA's Ames Research Facility is co-located with Moffett. The NASA ramp once bustled with activity ranging from Helicopter lift and noise research to the DC-8 flying laboratory and the recently retired C141 flying telescope.

In recent years, NASA and the Navy have significantly reduced flight operations at Moffett as part of their downsizing activities. Only an occasional transient NASA T-38 or USAF C-130 now occupies the enormous tarmac. Flight operations are also significantly reduced to transients and an occasional U.S. government contract air shipment from one of the many companies in Silicon Valley.

Like all military installations, the field is closed to all but official government business. The control tower is still active and averages 10 to 15 operations per day. But during a warm summer day last year — International Young Eagles Day — Moffett Federal Tower would handle a record 1,700 operations.

The planning for this event began almost a year earlier, just as the 1997 event was winding down. In order to hold this event at Moffett, EAA Chapter 62 had to secure the sponsorship of one of Moffett Field's Airfield Operations organization. Headed by Garey Tiffany, the group has sponsored Chapter 62 and the Young Eagle's program for the past five years.

Participation at this event has steadily grown year after year. This year's event was part of an overall larger group of events. A local radio station, KSFO - 560, sponsored the unfurling of the world's largest flag. More that 5,000 volunteers of all ages helped in the opening of the flag of the United States of America. A newcomer to this year's event was a Special Olympics "Pull a Plane" rally. Sponsored by Federal Express, the "Pull a Plane" pits local civic organizations in a tug of war with a Federal Express DC-10. The group that can pull the plane the farthest in the shortest amount of time is declared the winner. Proceeds go to help the Special Olympics.

Young Eagles is giving kids an opportunity that just isn't available anywhere else. Over 600 kids and 50 aircraft participated in the day-long event.

One of the reasons Chapter 62 has been able to continue to secure permission is the planning and dedication that the members put into this event. As in all Chapter 62 Young Eagles Events, areas of responsibility are defined and carried out by individuals within the chapter.

Chapter 62 member, Ray Hutchings, heads up pilots and flight volunteers. Ray admits that finding pilots for this event is no problem as his phone rings off the hook when word gets out that you can fly in and out of Moffett for this event. Ray also coordinates between NASA and Chapter 62 to ensure flight routing, flight safety and the always-present administrative paperwork functions are carried out.

Brian McShirley probably has the largest responsibility with his crew. They are responsible for the flight line safety and ground movement of both aircraft and people. Although Brian and his group of volunteers are just that, volunteers, each and every one performs their job in such a safe and professional manner that NASA's airfield management office has praised Chapter 62 for our safety approach both in the air and on the ground.

And of course, Young Eagles. Judy Stout and her team of volunteers have streamlined the registration process. Once the kids are signed in, Judy assigns them a number. When the child's number is up they fly with the next available pilot and plane. While the pilot and kids are airborne, Judy shuffles the paperwork and prepares the certificates. Just keeping the paperwork straight for an event of this size is a monumental task.

Like most Young Eagles rallies, this was the first time many of these youth have even been close to an airplane, let along able to fly. The flights typically lasted 20 minutes to a half an hour. The pilots and ground crews did their utmost to ensure this was a positive, memorable experience for both the child and the parents.

As the end of the day approached, a quick meeting with NASA's public relations chief Carl Honacker and the Moffett Federal Airfield's top leader, Geary Tiffany produced the praise "A job well done to all who participated."

We'll be looking forward to doing this again next year.

Editors Note: EAA Chapter 62's 1999 event is once again scheduled on International Young Eagles Day, June 12. No matter how small or large a Young Eagles event you may be a participant, we can all learn from Chapter 62's organization and attention to detail. Enjoy safely flying Young Eagles this year. We look forward to hearing your success stories in the months to come! By the way, don't forget to visit our new Gallery on the Young Eagle Flight Leader pages of EAA's web site. There you'll read about more success stories. ◆

We'd Like to Hear From You!

If you have photos and stories from your Young Eagle experiences, please feel free to share them with us. There are a number of ways to contact the Young Eagles Office.

Mail: Young Eagles, P. O. Box 2683,
Oshkosh, WI. 54903-2683

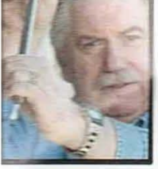
Phone: (920) 426-4831

FAX: (920) 426-6764

E-mail: YEagles@eaa.org

Young Eagles: www.youngeagles.com

Flight Leaders: www.eaa.org/youngeagles/index.html



Energy and Efficiency

Why are our piston aircraft engines so @#$%*! inefficient?

OUR PISTON AIRCRAFT engines convert chemical energy into mechanical work, but they don't do it very efficiently. It turns out that only about one-third of the energy contained in the 100LL we burn winds up getting to the propeller and doing useful work to propel us through the air. The remaining two-thirds winds up getting lost between the fuel truck and the prop hub. At today's stratospheric avgas prices, that's pretty depressing.

LET'S DO THE MATH

Consider a Continental IO-550 engine rated at 300 hp. If the fuel system is set up properly per Continental Service Bulletin SID97-3F, fuel flow at maximum takeoff power is about 26.6 gallons/hour or 156 pounds/hour. How much chemical energy does that fuel provide?

We can calculate that. 100LL is rated at a "minimum lower heat value" of 18,700 BTUs per pound. Let's convert that figure into something more meaningful to pilots like you and me.

(1) Divide 156 pounds per hour by 3,600 seconds per hour to get 0.0433 pounds per second.

(2) Multiply by 18,700 (the thermal content of 100LL in BTUs per pound) to get 810 BTUs per second.

(3) Multiply by 1.414 (the horsepower equivalent to 1 BTU per second) to get 1,146 hp.

Does this mean that your IO-550 consumes 100LL with thermal energy equivalent to 1,146 hp, and yet produces only 300 hp of output power? Unfortunately, that's *exactly* what it means—and that works out to a miserable thermal efficiency of 26 percent. Good grief!

Should an IO-550 really be drinking this much fuel? Well, we can calculate that, too.

(1) At takeoff power, the engine is turning at 2700 rpm. Since it's a four-stroke engine, each power cycle requires two crankshaft revolutions. Therefore, the engine is operating at 1,350 power cycles per minute.

(2) The displacement of the engine is 550 cubic inches, or 0.32 cubic feet. Due to induction system losses, however, the engine's "volumetric efficiency" is only about 85 percent, so it "inhales" only about 0.27 cubic feet of air per power cycle.

(3) Multiplying 1,350 power cycles per second times 0.27 cubic feet of air per cycle, we calculate that the engine should inhale 365 cubic feet of air per minute.

(4) Sea level air under standard atmospheric conditions weighs 0.0765 pounds per cubic foot. Therefore, the engine breathes 27.9 pounds of air per minute.

(5) Best power mixture requires an air-fuel ratio of about 12.5 to 1 by weight. Dividing 27.9 by 12.5, we get a fuel burn of 2.23 pounds of fuel per minute—or multiplying by 60, we get 134 pounds per hour or 22.3 gallons per hour calculated fuel flow at best power mixture.

The actual book fuel flow figure of 26.6 gallons/hour or 156 pounds/hour is higher than this calculated value because of the unusually rich mixture required to provide adequate detonation margins at full take-off power.

WHAT ABOUT LOP?

Surely engine efficiency is much better at cruise power settings with aggressively lean mixtures, right? Let's take a look. An IO-550 engine running at 65 percent power and operating LOP uses approximately 13 gallons/hour or 78 pounds/hour. What kind of thermal efficiency does that represent? Repeating the calculations:

(1) Divide 78 pounds per hour by 3,600 seconds per hour to get 0.0217 pounds per second.

(2) Multiply by 18,700 (the thermal content of avgas in BTUs per pound) to get 405 BTUs per second.

(3) Multiply by 1.414 (the horsepower equivalent to 1 BTU per second) to get 573 hp.

So even at LOP cruise, the IO-550 consumes 573 hp worth of go-juice in order to produce 195 hp (65 percent of 300), for an efficiency of about 34 percent. Definitely better, but certainly nothing to write home about.

WHY SO WASTEFUL?

Here's one breakdown of efficiency losses (from *Performance of Light Aircraft* by John T. Lowry, Ph.D.):

Otto cycle efficiency—the thermodynamic efficiency of a four-stroke internal combustion engine—is limited by the compression ratio (i.e., the ratio of cylinder volumes as the piston moves from bottom-dead-center to top-dead-center). The higher the compression ratio, the greater the efficiency. For an IO-550 with a compression ratio of 8.5-to-1, the Otto cycle efficiency works out to about 57.5 percent.

Volumetric efficiency—As mentioned earlier, the ability of the engine to breathe in its full theoretical displacement of air during each power cycle is restricted by a variety of pressure losses at various points in the induction system: air filter, throttle body, intake manifold, and intake valves. For most of our engines, volumetric efficiency is around 85 percent, bringing total efficiency down to 57.5 percent times 85 percent, or 49 percent.

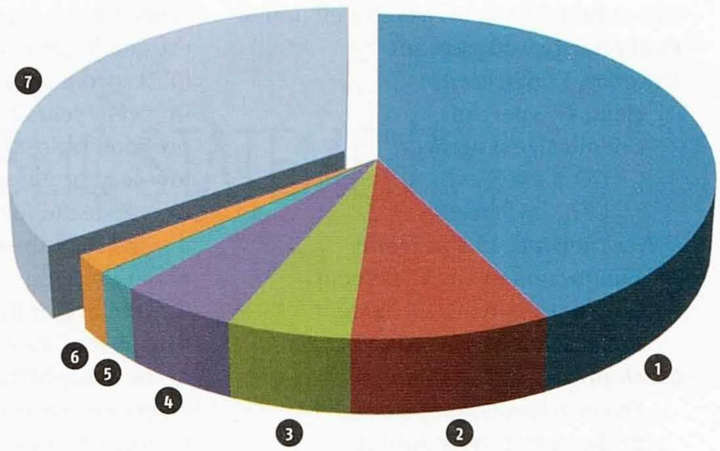


Figure 1: Functional breakdown of efficiency losses by John T. Lowry, Ph.D. 1) Otto Cycle, 2) Volumetric, 3) Mixture, 4) Mechanical, 5) Accessory, 6) Other, 7) Net Power Output

Mixture losses—Optimum fuel efficiency occurs at very lean mixture settings (so-called "best economy mixture") with an air-fuel ratio in the vicinity of 18-to-1 by weight. Best economy mixture occurs very LOP, however, and most pilots don't operate that lean. (Not to mention that many engines won't run smoothly that lean.) Many pilots operate rich of peak EGT in the vicinity of best-power mixture, at an air-fuel ratio around 12.5-to-1, which provides a fuel efficiency that's only 70 percent of optimum. Even if you operate slightly LOP (let's say at an air-fuel ratio of 16-to-1), your efficiency is just 89 percent of optimum, and that brings total efficiency down to 49 percent times 89 percent, or 44 percent.

Mechanical losses—Friction losses involving the reciprocating and rotational parts inside the engine consume a significant amount of power that could otherwise be delivered to the propeller. Mechanical efficiency varies with engine speed (lower losses at lower rpm), but is typically around 88 percent, bringing total efficiency down to 44 percent times 88 percent or 38 percent.

Accessory losses—A certain amount of engine power is consumed driving accessories such as magnetos, fuel pumps, alternators, vacuum pumps, hydraulic pumps, air conditioning compressors, etc. Figure this robs 5 percent of the remaining power, bringing total efficiency down to 36 percent.

Other losses—This includes a grab bag of other inefficiencies including blow-by past the piston rings, unburned hydrocarbons in the fuel, humidity in the air, back pressure in the exhaust system, and so forth. Figure another 5 percent loss, bringing total efficiency down to 34 percent (which agrees with our earlier figure for an IO-550-B at 65 percent LOP).

THERMAL AND CHEMICAL LOSSES

A quite different analysis (from *Fundamentals of Power Plants for Aircraft* by Joseph Liston) analyzes the various thermal and chemical losses suffered by a piston aircraft engine.

We've already seen that an internal-combustion engine is incapable of converting all the heat of combustion into mechanical energy, limited primarily by its finite compression ratio. The rest of the heat of combustion, as well as a small amount of additional heat generated by friction, is lost through the engine's exhaust and cooling systems.

There are also some chemical losses. In theory, the combustion of pure hydrocarbon fuel at stoichiometric mixture should produce nothing but carbon dioxide (CO_2) and water (H_2O). In reality, however, there's always some sulfur in the fuel, which is transformed by combustion to sulfur dioxide (SO_2) and sulfuric acid (H_2SO_4). If the mixture is a bit on the rich side, the exhaust also contains carbon monoxide (CO), which results from incomplete combustion, as well as some unburned carbon particles and some methane gas (CH_4).

ILLUSTRATION COURTESY OF **MIKE BUSCH**

Here's how Liston breaks this all down:

Fuel energy, 100 percent

Exhaust, 51.6 percent

Heat, 47.0 percent

Chemical, 4.6 percent

CO, 3.1 percent

CH_4, 1.5 percent

Other thermal, 12.2 percent

Conduction to air, 7.2 percent

Conduction to oil, 1.6 percent

Radiation and misc., 3.4 percent

Mechanical, 36.2 percent

Friction losses, 4.3 percent

Brake horsepower output, 31.9 percent

Again, this figure agrees pretty well with our earlier 34 percent figure for the IO-550-B at 65 percent LOP cruise.

CAN WE DO BETTER?

What, if anything, can we do to improve this dismal efficiency? Well, don't expect any miraculous improvements of large magnitude. But every little bit helps, and there are certainly a few areas where the potential exists for improvement.

Otto cycle efficiency—As we've seen, the basic thermodynamic efficiency of an internal combustion engine is a function of compression ratio. Unfortunately, high-compression engines have traditionally required high-octane gasoline in order to avoid detonation, and high-octane gasoline is fast becoming unobtainable because of the campaign to eliminate tetraethyl lead (TEL) from avgas. Consequently, the trend in recent years has been toward lower compression ratios that are compatible with low-lead or unleaded fuel. While this may be wonderful for the environment, it sure doesn't help the thermodynamic efficiency of our engines.

One bright light on the horizon is the prospect of moving from fixed-timed magnetos to sophisticated, computerized electronic ignition systems capable of protecting engines against detonation by varying ignition timing. The incorporation of variable ignition timing and detonation sensors should permit the use of higher compression ratios even with unleaded fuel. It may take a few more years before any such systems make it through FAA certification, but the prospects for improved efficiency are significant.

Even more exciting is the recent advent of certificated diesel engines for piston aircraft, which run on Jet A and have 18-to-1 compression ratios that offer much greater thermal efficiency than any spark ignition gasoline engine.

Volumetric efficiency—Small improvements in this area are possible through the use of tuned induction systems, large intake valves, venturi-style valve seats, ram recovery air scoops, and turbocharging. Auto engines have even gone to multiple intake valves per cylinder, but the weight and complexity might make this impractical for aircraft engines.

Mixture losses—Major strides have already been made in this area, partially through pilot education to encourage the use of lean mixture settings, and partially through improvements to engine instrumentation and mixture distribution to facilitate operation at or near best economy mixture (i.e., considerably LOP).

Mechanical losses—The biggest thing that can be done to reduce mechanical losses is for pilots to cruise at low rpm and high manifold pressure, rather than vice versa. Small additional gains are possible through the use of high-lubricity synthetic oil to reduce friction losses, but the leading all-synthetic oil (Mobil AV 1) was pulled off the market in the 1990s due to its inability to control lead deposits, and even semi-synthetics like AeroShell 15W-50 have lead-deposit problems, particularly in small-sump engines like the ones used in the Cessna TTX and Cirrus SR22. When the lead is ultimately removed from avgas, all-synthetic oils may come back in favor for piston aircraft engines.

Accessory losses—The conversion to electronic ignition systems may also provide some small benefits by eliminating the mechanical losses involved in driving dual magnetos, although this may be partially offset by the requirement for electronic-ignition engines to have dual alternators. The trend toward all-electric airplanes with no pneumatics or hydraulics may also help slightly.

For now, the best thing you can do to improve efficiency is to lean aggressively (considerably LOP if feasible), and to cruise at low rpm and high MP rather than vice versa. In the foreseeable future, further improvements may be possible through the use of variable-timing electronic ignition systems and installation of higher-compression pistons. Efficiencies in the area of 40 percent are possible, but don't expect much more than that from spark-ignition engines, at least any time soon. EAA

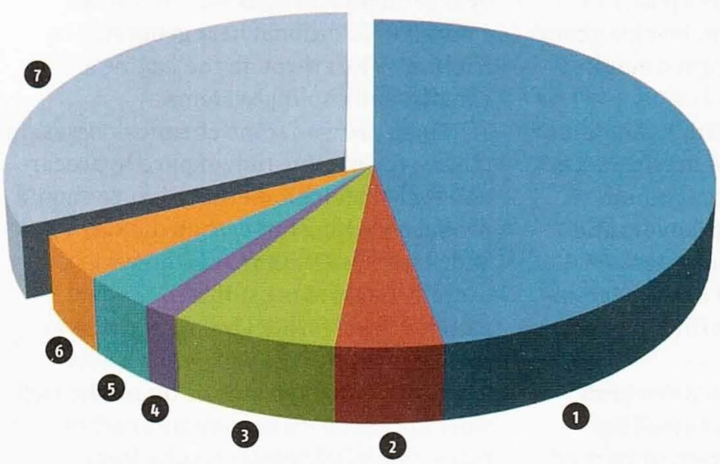


Figure 2: Thermal and chemical breakdown of efficiency losses by Joseph Liston. 1) Exhaust [Heat], 2) Exhaust [Chemical], 3) Conduction to Air, 4) Conduction to Oil, 5) Radiation and Misc., 6) Friction, 7) Net Power Output

Mike Busch, EAA 740170, was the 2008 National Aviation Maintenance Technician of the Year, and has been a pilot for 44 years, logging more than 7,000 hours. He's a CFI and A&P/IA. E-mail him at *mike.busch@savvyaviator.com*. Mike also hosts free online presentations as part of EAA's webinar series on the first Wednesday of each month. For a schedule visit *www.EAA.org/webinars*.

ILLUSTRATION COURTESY OF MIKE BUSCH

LONG-EZ
WITH A PURPOSE

ARTICLE AND PHOTOS BY JEFF RICHMOND

Tim prepares to depart First Flight Airport on a research mission. The Wright Brothers Monument is in the background.

Tim Crawford is not the first pilot to start building an airplane before he took his first flying lesson, but how many pilots have flown more than 3,000 hours on their third aircraft in fewer than 10 years?

Tim — a Ph.D Engineer for the Tennessee Valley Authority at the time — first learned that it was possible to build and fly his own airplane when he attended an EAA Fly-In at Tullahoma, TN in 1980. At that event, he met and talked with Burt Rutan, and the rest, as they say, is history. It took Tim three years to build his first Long-EZ.

Tim has been involved in building five aircraft: two Long-EZs, two twin-engine Defiants, and a Velocity. He sold the first Long-EZ about a year after it was completed, and went into a partnership to build the first Defiant. In Tim's words, "The Defiant is a massive homebuilt project. The first was built in one year and flown to Oshkosh." The second Defiant was actually his fourth aircraft, but he sold it when only 80% complete because he "fell in love" with the Velocity Elite RG, "with its gull wing doors" — which he still has.

By the time he had started his third aircraft, Long-EZ N3R, Tim had gained enough experience to make some changes. "I started building N3R on my birthday in September 1985. It was finished on July 4, 1986." The changes in the design were driven by the instrument panel. "At the time I was excited about IFR and I knew I wanted a serious IFR aircraft. So, I built the instrument panel first. It was three inches wider to fit the instruments I wanted. The three inches set the scale for the rest of the fuselage.

"From there, I modified the design from the ground up," Tim explained. "I also wanted more shoulder room. I made the fuselage 4 inches wider, 2 inches deeper, and 14 inches longer. The 14 inches come from a 12 inch longer nose and 2 more inches of leg room in the back. The wings are 4 inches longer and the winglets are 3 inches taller." Tim adds, "Neil Hunter inspired me to build my second Long-EZ after he let me fly his 'Big-EZ' which was 7 inches wider." Tim has decided that N3R is a "keeper."

N3R incorporates other enhancements over Rutan's original design. The airframe is stronger to withstand +9, -6 Gs and is certified for aerobatics. Tim says, "To get N3R certified for aerobatics, the FAA required I demonstrate aerobatics during a test flight. However, I never worked at it so I have never gotten really good. I can still do a clean loop and a roll — sometimes," he adds with a big grin.

The fatigue-resistant, high-strength composite structure allows safe operation in the extreme turbulence often encountered during low-level operations. Twenty percent larger than a standard Long-EZ, N3R is powered by a 160 hp Lycoming O-320. It has an empty weight of 950 pounds and a maximum gross takeoff weight of 1,800 pounds.,

Tim has had three propellers on N3R. "The first was a two-blade prop from the Great American Propeller Company. It worked great," Tim said, "but I thought I could make a better one, so I designed and made one with thinner blade sections wrapped in carbon fiber. It was a few knots faster, but the stiff blades increased the takeoff roll."

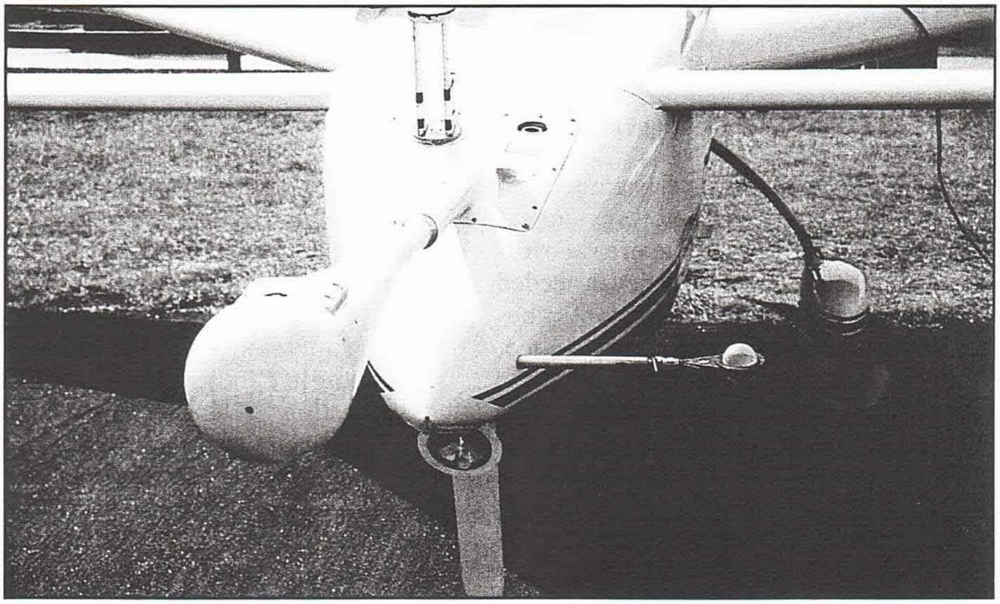
N3R now has a three-blade propeller. Tim explained why. "About five years ago both props were damaged by rocks on runways in Barrow, Alaska — talk about a freeze-thaw problem. Anyway, I repaired both props, but I knew I had to do something to stop the problem. The two-blade propellers were too long. I knew a three-blade propeller could absorb the horsepower with less diameter, but, to my surprise, N3R is even faster and quieter with the new prop." Tim reports that the new prop gives N3R a full-throttle speed of 175 kts. indicated at 8,500 feet.

N3R also carries a BRS ballistic recovery parachute system. This can be deployed in less than a second. The canister containing the chute is bolted to the center-section spar. A very thin fiberglass "blow out" patch is installed above the canister for chute deployment. The chute is tied to the airframe with a three-point Kevlar harness, configured to lower the aircraft in a level attitude. A 4-point 40 G restraint harness and safety-foam crash seats are also part of the safety equipment.

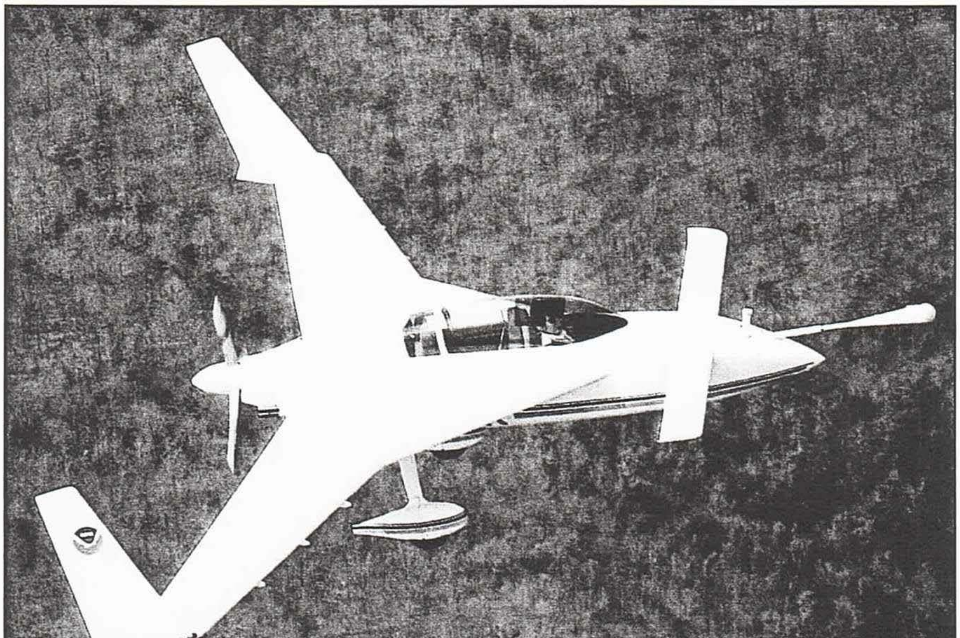
When not instrumented for research, N3R carries two people with limited baggage. The expanded 73 gallon fuel capacity provides up to 10 hours endurance at 200 mph. An optional long-range fuel tank can be installed, increasing fuel capacity to a total of 100 gallons and extending range to 3,500 miles, sufficient to ferry the aircraft anywhere in the world.

N3R is fully IFR-equipped with a two-axis autopilot, dual nav-coms, an IFR GPS receiver, a Stormscope and an oxygen system.

In 1990, Tim went to work for the National Oceanic and Atmospheric Administration's Air Research Laboratory. His assignment was to work with the Atmospheric Turbulence and Diffusion Division (ATDD) in Oak Ridge, TN. ATDD had been established in 1947 to study the wind and weather around Oak Ridge to predict possible dispersion patterns of radiation and

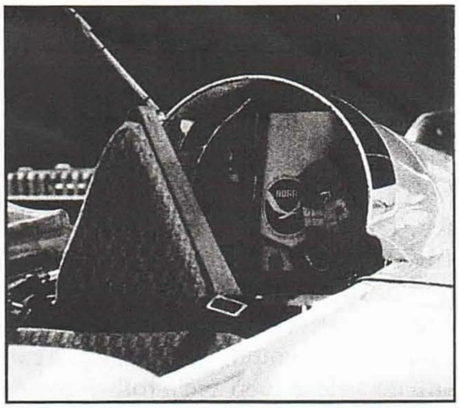


The BAT probe extends ahead of the aircraft in undisturbed air. Holes on the spherical surface detect winds from all directions and angles. The vertical instrument at the base of the probe is an infrared gas analyzer that measures water and carbon dioxide. The square antenna on top of the probe is one of the Trimble TANS Vector System antennas.



Tim Crawford pilots his research-instrumented Long-EZ. The BAT probe senses crosswinds as well as vertical air currents. The aerodynamic shape and pusher-prop configuration of the Long-EZ allow the BAT probe to penetrate undisturbed air. The infrared water vapor and carbon dioxide sensor is located at the base of the probe. Tim is the director of the Idaho Falls NOAA Field Research Division, which explains the NOAA insignia on the winglets.

N3R at the site of the flight of another famous canard aircraft — the Wright Flyer.



The BRS parachute system is nestled behind the rear cockpit. There is a lightweight blow-out panel directly above the canister for chute deployment.

chemical gases if they were accidentally released from one of the nuclear research facilities in the area. Fortunately, their studies were never needed for their intended purpose, but it became apparent that their experience, methods and facilities could be used to study industrial pollutants, global warming, greenhouse effects and related atmospheric research.

A key to these studies is the pattern of air movement near the surface. It was determined that understanding vertical air currents could help predict the transfer of carbon dioxide and other substances between the ground, vegetation and the air. This information could have a significant impact on our understanding of the chemistry and concentration of greenhouse gases. Originally, research was conducted using instrumented towers to monitor air movements. Although effective, each tower could collect data from only one location.

Tim and his colleagues realized that it was necessary to take measurements over a large area in a short period of time in order to fully understand the atmospheric effects they were studying. With this in mind, Tim set out to equip his Long-EZ as a research aircraft.

Much of N3R's research involves detecting and measuring wind. Consider this challenge: not only detect, but measure the direction and speed of a wind about as strong as a child's breath as you fly by at 100 mph. That challenge was solved using the most prominent feature on N3R, the BAT ("Best Aircraft Turbulence") probe, which Tim invented. A radial pattern of nine equally spaced holes on the spherical end of the BAT can detect wind speeds as light as two centimeters per second from any direction — vertically to horizontally.

Wind measurements from an airplane are simple in concept. To compute the average horizontal wind the only information needed is ground track, ground speed, true heading and true airspeed. From these four variables, a wind triangle can be solved for the wind direction and speed. Tim's BAT and the support software solve the "wind triangle" in three dimensions.

The Long-EZ is an ideal platform for this research. The clean aerodynamic shape of the aircraft and the pusher prop allow the BAT to sample undisturbed air in front of the aircraft. The onboard differential GPS and a Trimble TANS Vector System, with four antennas located on the upper surface of the aircraft can determine aircraft position within ±3 m, velocity within ±2 cm/s, and attitude angles (pitch, roll and heading) within ±0.05 of a degree. This data is sensed at a rate of 50 times per second (50 Hz). This allows the onboard computing system to accurately compensate for aircraft speed and attitude and solve the wind triangle for very light wind currents.

To fully understand what is happening in the environment, sensors also measure air temperature, water vapor, carbon dioxide, ozone levels, dew point, and surface temperature. When required, the aircraft can be equipped with a laser altimeter and video cameras. Tim also has a pod-mounted Ka-band radar altimeter that can be mounted under the center of the fuselage.

Using the Long-EZ in field research is straightforward. When fully instrumented, the rear cockpit is occupied by a computer and instruments. Because only one pilot flies the airplane to collect data, the data acquisition system is highly automated. The onboard research computer is a fast PC-type computer capable of collecting and processing up to 32 sensor signals, also at a rate of 50 Hz. This means data is collected and recorded approximately every meter at a speed of 50 m/s (approximately 100 kts.). The computer completes all of the preliminary computations to provide wind data. After each flight the computer data is saved on disks for more detailed analysis.

Tim has conducted research flights in his Long-EZ from Florida to the North Slope of Alaska, and Hawaii. One of their more recent projects involves studying the interaction between winds and waves in coastal waters. Conducted in collaboration with the Office of Naval Research, Oregon State University, and the National Center for Atmospheric Research, the research is intended to better understand the relationship between waves, wind, coastal geography, and water currents. The Navy expects to use this data to improve targeting systems for sea-skimming missiles.

For this research, N3R was equipped with both a sensitive radar altimeter and a laser altimeter. The laser altimeter can measure the difference in height between the trough and crest of a wave with an accuracy of ±1 cm. At the same time the local wind speed and direction, air temperature, and humidity are recorded. During one three week period in March 1999, flying out of First Flight at Kitty Hawk, NC, Tim and fellow scientist/pilot Ed Dumas flew more than 75 hours, collecting data that may take two months to analyze and understand.

A typical mission for the Long-EZ lasts from three to six hours. Each flight begins with detailed preflight planning of the track to be flown, altitudes, weather, communications schedules, and safety and contingency plans. If the flight time to be flown in one day exceeds six hours, Tim and Ed split the flying duties. While conducting research flights over the North Slope of Alaska, Tim and Ed logged 21 hours during four flights in one day. When the aircraft lands, members of the research team collect the computer data and take it back to the local operations center and download it for preliminary analysis. Although it may take several months to fully analyze the data, the research team can get enough information to adjust the flight plan for the next day.

During field experiments, a field office is set up in a local hotel room with telephone service, electric power, and access to the roof or other open space for the GPS and VHF antennas. The field office is equipped with data processing computers, Internet access, a GPS ground station, and radio communications. From the field office, the research team and the scientist/pilot evaluate weather, plan missions, file flight plans and, if required, reserve airspace.

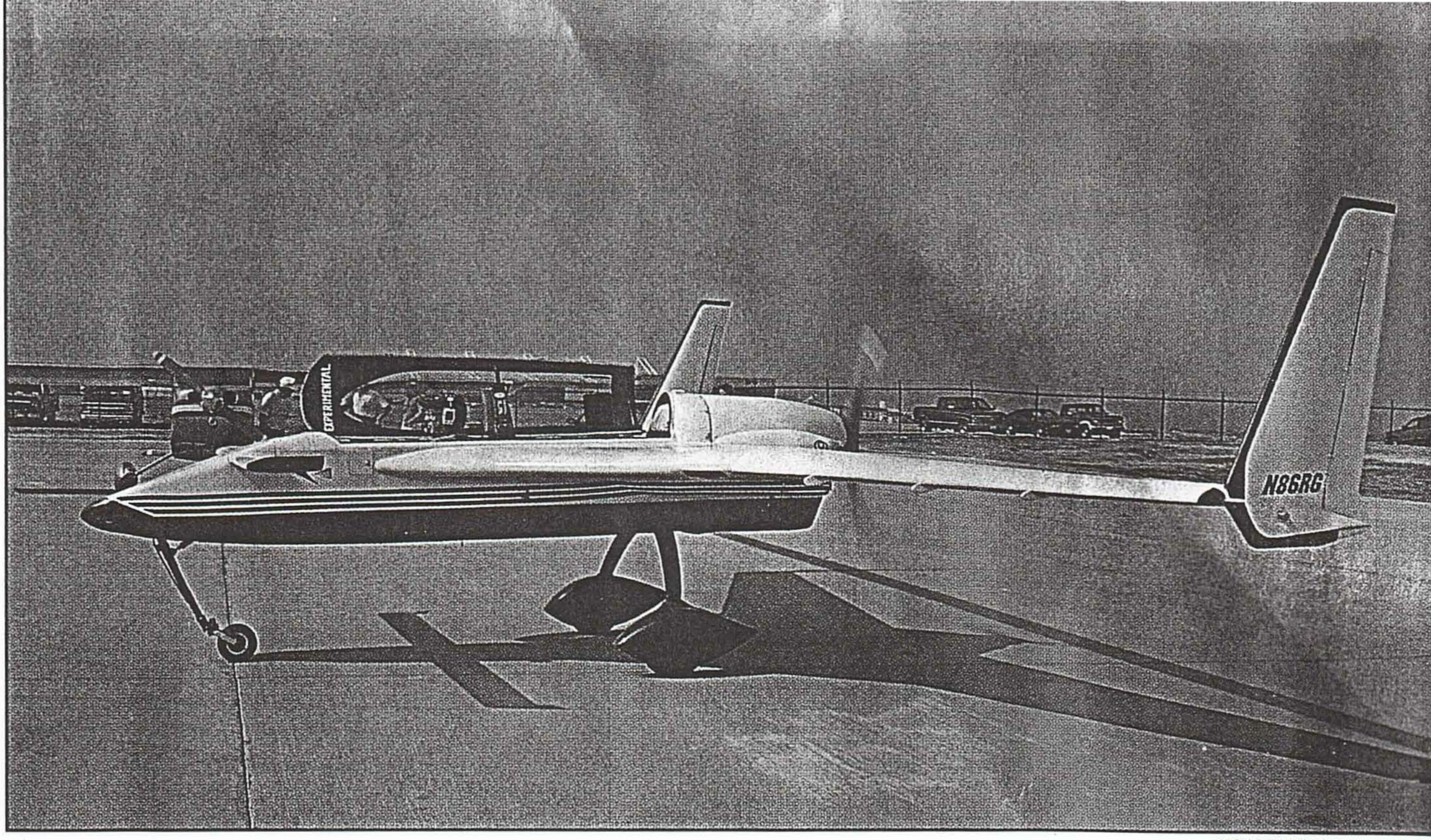
Flight safety is the first issue addressed in program planning, deployment, and daily operations. Both Tim and Ed are experienced commercial instrument-rated pilots. The scientific efficiency of their research is enhanced because the pilots are also scientists and members of the research team.

N3R offers significant advantages over other research aircraft. Lockheed P-3s and C-130s are great for flying into hurricanes, but are not operationally or economically feasible for extended low-level research. The Long-EZ's low operational cost allows researchers to gather significantly greater amounts of data within their budgets, and allows smaller research programs to have access to a research aircraft. N3R also operates in remote regions with minimal on-site support. Using a local airport near a research site enhances research efficiency by reducing ferry time to the research area.

Another advantage of the Long-EZ is that it is relatively quiet, and its unusual shape typically attracts favorable comments rather than citizen complaints. Tim is quick to point out that all flights are conducted in compliance with Part 91 of the Federal Aviation Regulations, including the minimum altitude restrictions. Operations over water have few restrictions except that appropriate survival and navigation gear are carried.

Tim takes his science, research, and flying seriously. What would be a dream job for many pilots is a passion for Tim. First, Tim says he wants their research to be useful, not just for scientific purposes, but to help resolve problems that will improve the environment — and people's lives. When talking about his aircraft, Tim is frequently heard to say, "It's not about the flying. It's about the science." Understanding and properly managing our environment fits into his sense science and purpose. And he gets to fly a lot doing it.

Note: For the record, Tim is also an EAA Technical Advisor. For more information about Long-EZ N3R, go to www.atdd.noaa.gov.long_ez. For details on Tim's BAT, check out www.atdd.noaa.gov/bat/bat.htm. This page also has links to Tim's research and related sites. ◆



JACK COX PHOTOS

A LONG-EZ THAT GOES HM-M-M-M

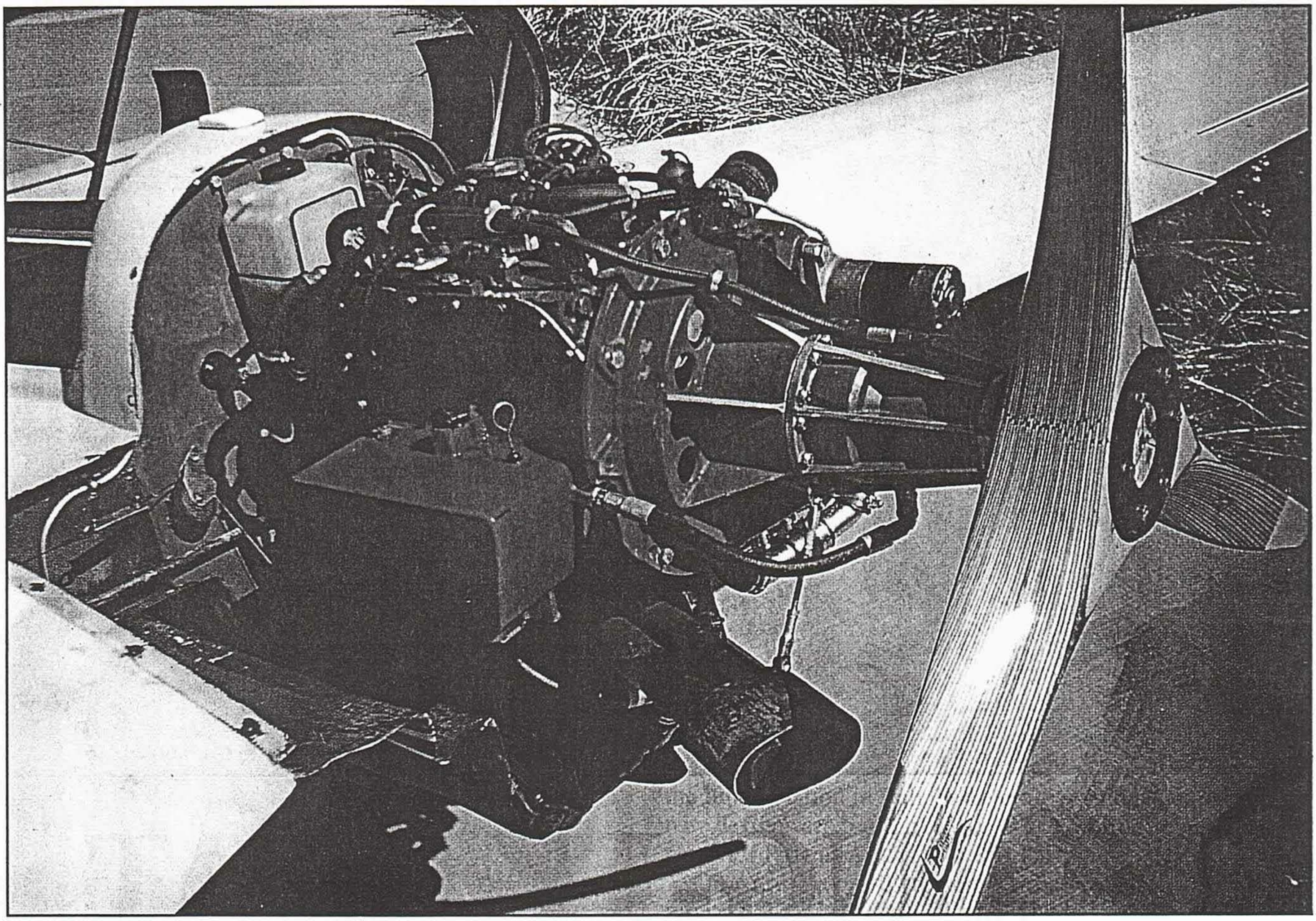
Power by Mazda

BY DICK CAVIN

If you were one of the fortunate ones who attended Oshkosh '95 you probably noticed there were two full lines of auto engine powered homebuilts on display. If you saw the extra heat around the area, it was probably the result of imaginations being set afire again.

One of those who caused blood to pound in EAAers veins again was a Mazda 13B powered Long-EZ by a young Delta Airlines mechanic, Ron Gowan of Roanoke, TX.

It was a decade or so back when news of the NSU Wankel rotary reached the U.S. and excited EAAers with the prospect of a turbine-like en-



gine at salvage yard prices.

Cold water was thrown on that dream when Cessna terminated a year long test of a Curtiss Wright rotary in a C-182, supposedly because of excessive fuel burn, among other objections.

In that era, long time EAAer Harold Gallatin showed up at the annual Convention with a single spool Wankel rotary mounted on the back of a pickup, running it often to the delight of spectators.

For reasons not totally clear, there was an almost total dearth of news about the rotary engine in homebuilts for over a decade. Mazda did have problems with early engines, but since 1986 when they put the present 13B engine in the RX-7 (a $30,000 luxury sport), it's been a jewel of an engine.

In 1978 Jim Thompson of Tucson, AZ put an earlier Mazda 12A in a BD-4, with only so-so results. A few years ago I did an article on a single spool Mazda in an ultralight that Gene Eubanks of McKinney, TX built and flew, but this didn't evoke a great groundswell of interest in the rotary powerplant at that time.

Ron Gowan had bought Long-EZ plans in 1985 and in two years he was flying it with a used Lyc. O-235 (with 430 hours since new). After he had put 300 hours on it, it got sick enough to need a top overhaul. The bill was $2200! After another 400 hours it shelled out on him and this time he had had enough.

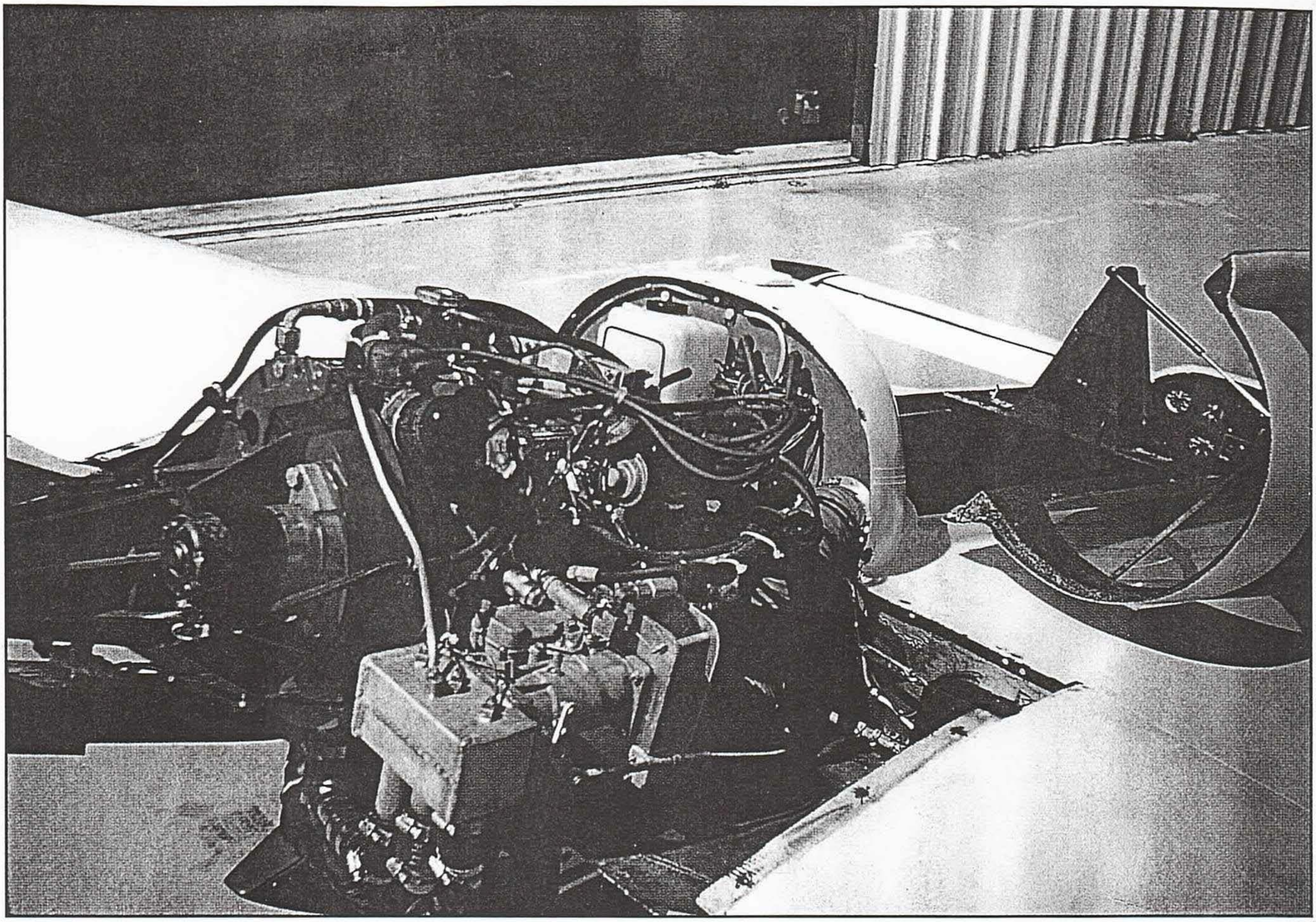
In the meantime, Ron had started on still another project, a non-sanforized version of Rutan's Defiant twin pusher, to be powered by two Mazda 13B rotaries. This one would have to stay in limbo awhile, as he would have to rob it of one of its two powerplants.

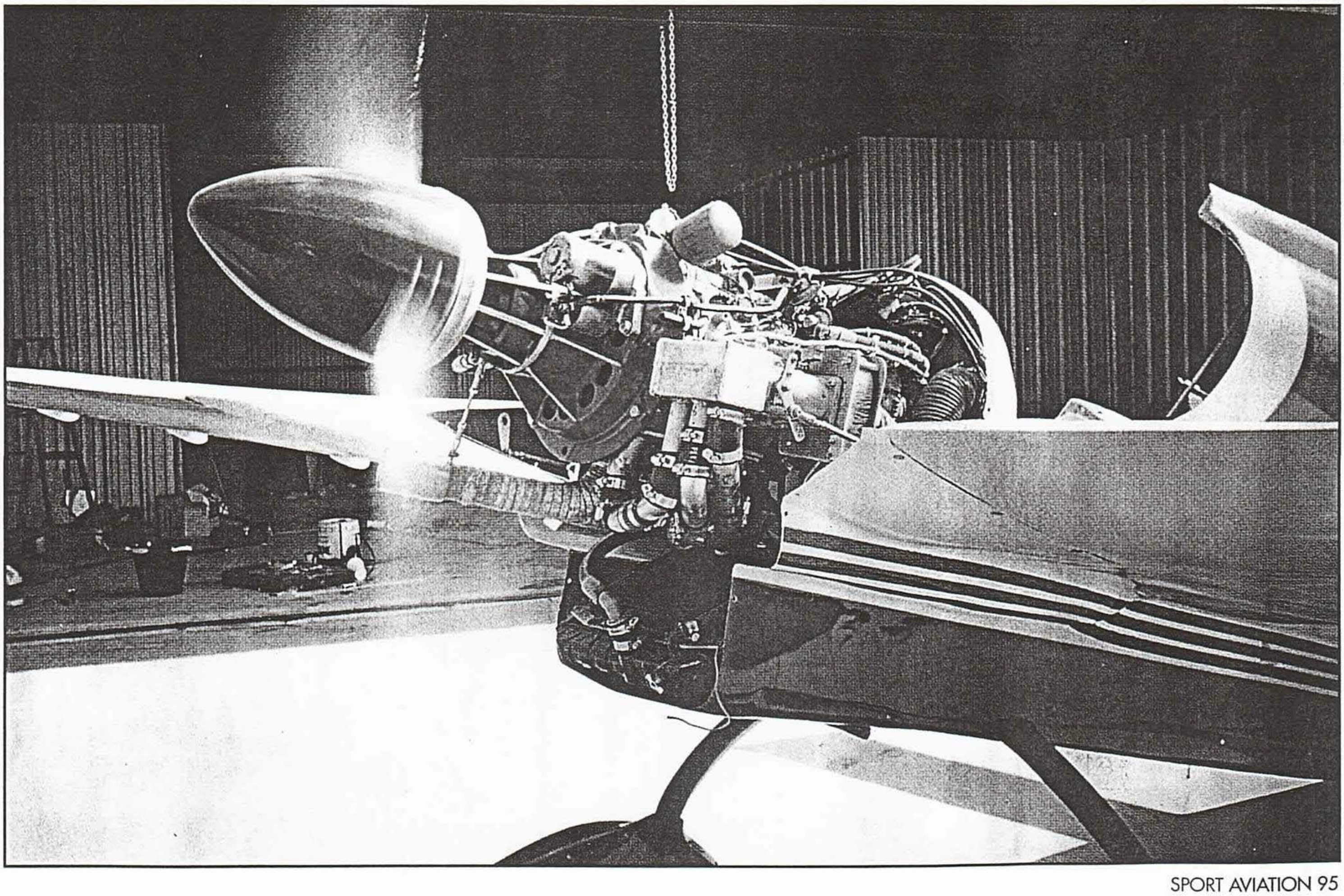
Ron had bought two Mazda 13Bs, an '87 and an '89, for $1000 each, so he chose the best of the litter—the '89—with only 13,000 miles on it. His exceptional mechanical talents started to show up here. A new cowling and motor mount were obviously necessary, so he removed the old firewall and made a dummy from it.

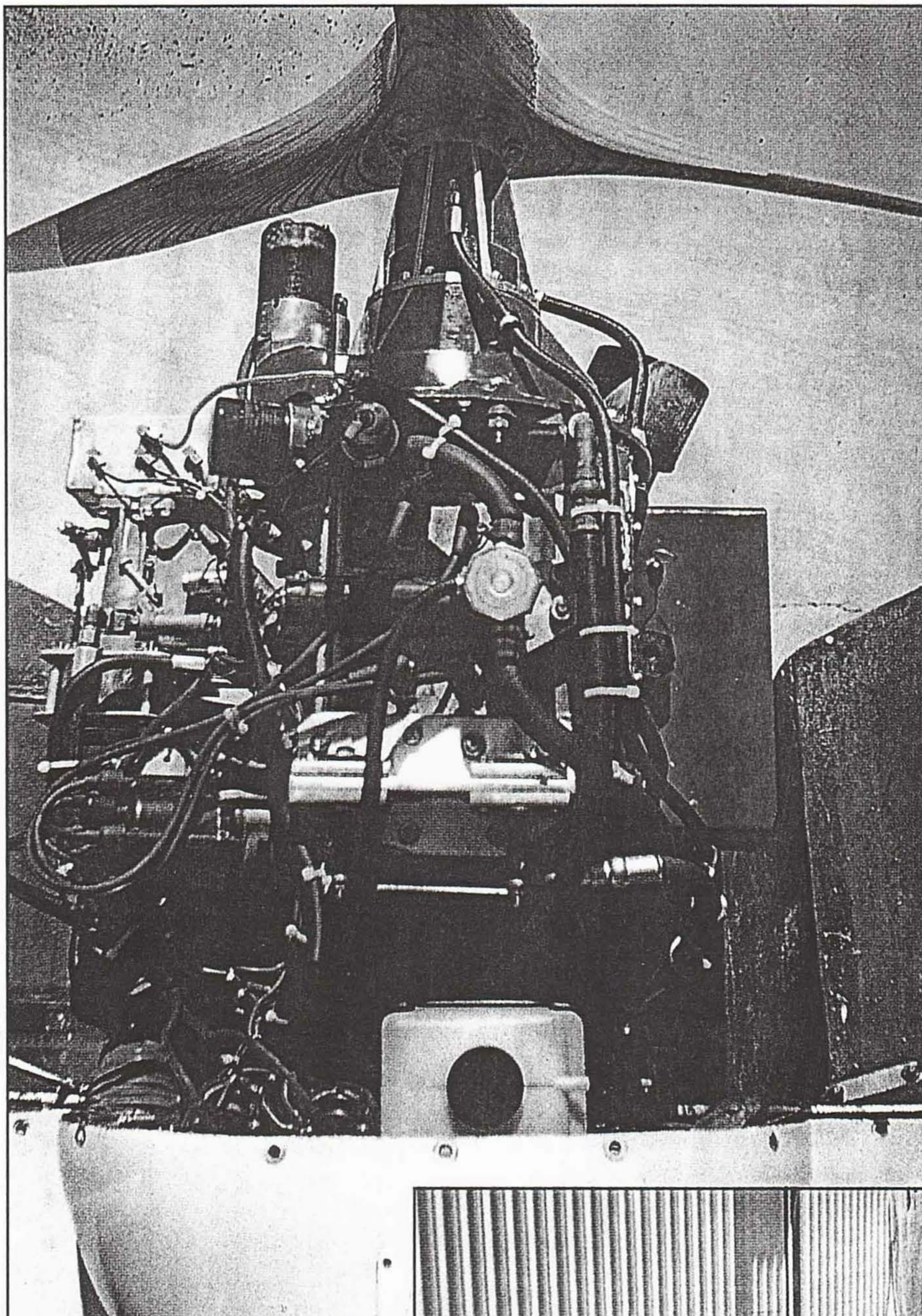
After rechecking his CG figures, he laid the firewall on the bench, hanging the engine above it from the ceiling on a hoist. Using 5/8" PVC pipe and a hot glue gun he made a dummy engine mount (slick, huh?). He then fabricated a welding jig around the PVC mount and welded up the mount from 5/8" x .049 4130 tubing, using Rutan's engine mount plans as a guide.

Paring off every excess ounce of weight, he chose to use a Geo Metro alternator, saving 3 lbs. over the original (and some space). The Metro alternator fit like it was made for it. For the carburetor he chose the Marvel Schebler HA-6 aircraft carb (cost $200 vs $1200 for a fuel injector), a side draft design, again saving a little weight and giving him a high CFM flow. He built up an aluminum plenum chamber 3" x 3" x 6" downstream from the carb, with an air filter upstream of the carb, with a ram air valve further upstream on the firewall.

His ingenuity again showed as he designed and fabricated his intake manifold, which runs about 24" from the plenum chamber to the intake ports. To eliminate expensive bendings he used parts of six 1-1/2" steel sink drainage pipes, held together with 1-1/2" radiator hose and hose clamps.





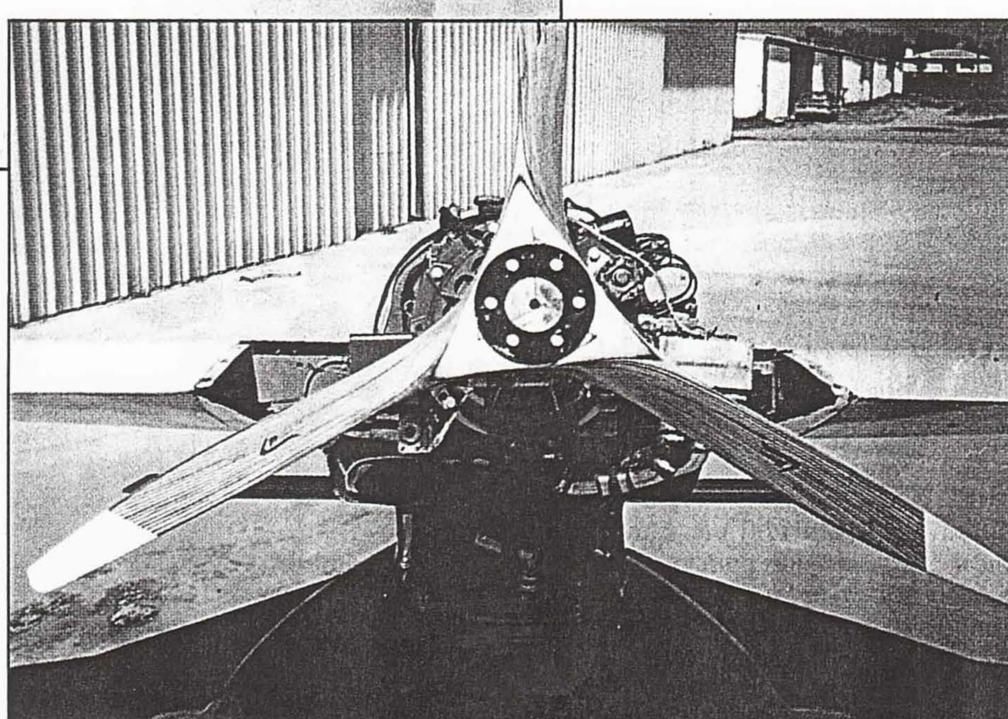


max static rpm increased from 5600 to 5800!

Ron used the stock 1985 Mazda vacuum advance distributor with point ignition system, mounting the two ignition coils vertically on the firewall. The 4 spark plugs are stock Mazda, look like aircraft plugs, and are expensive. Ron said, "So I can sleep better," he installed two small batteries in the nose. Both are independent and are charged through an isolator circuit, which he purchased at an RV shop. This guarantees electrical reliability, even though the alternator might fail. The electrical system also operates the two facet electric fuel pumps, one of which is a backup, since there is no engine driven fuel pump.

For additional reliability Ron purchased a special pulley from Racing Beat in California, which is 3/4" smaller in diameter than the stock pulley, which drives both the water pump and the alternator, reducing accessories rpm by 50%. Two separate belts are used, so that if the first belt (driving the water pump and alternator) should break, the second belt drives the water pump only.

For the cooling system Ron uses a Honda Civic radiator and a J.C. Whitney oil radiator mounted underneath the engine in a tandem arrangement, tightly sealed in a plenum chamber. Intake cooling air is via a manually controlled movable



From the exhaust ports to the pusher prop in the Long-EZ is rather short and he designed and fabricated his own of stainless steel 2-1/2" dia. tubing. His first engine testing showed even idle rpm exhaust noise was . . . well, fierce, unacceptable. It definitely needed a muffler of some sort. Ron plugged the ends of the pipes and drilled a series of 1/2" dia. holes several inches back. He then built a shroud around the pipe, with about a 1/2" gap between it and the pipe. Not only was the noise now well within the acceptable range, but surprisingly the door on a belly mounted NACA scoop. Both radiators are set at about a 45° angle to the firewall to face incoming air squarely. There is also another small radiator in the nose, connected to the engine via a 5/8" aluminum line. This radiator also doubles as a cabin heater in cold weather.

Ron chose not to use a thermostat, knowing that if the $5 thermostat fails in the closed position it could be a mighty expensive lesson. A plastic coolant overflow bottle is mounted on the upper firewall. The system is filled with 5 quarts of standard 50/30 coolant mix.

At cruise the coolant runs at 13 lbs. of pressure with coolant temperature varying with OAT. On a 100° day the system can reach 200-210°F at extended full power down low, but on a cold day he can fly at full power down low and not exceed 175°F. The NACA dust and radiator position form an inlet diffuser somewhat like the P-51s.

Ron formerly used an auxiliary cooling fan for ground cooling, but it quit after some 40 hours of running, possibly because it was windmilling too fast. Right now ground cooling is pretty poor without it, especially after a low level flight on a hot day, but he's working on that problem.

The Mazda 13B installation has been relatively trouble free, except for a nuisance type oil leak around the gear box seal. He cured that by going to a double edge seal around the Ross Aero bell housing adapter and venting the oil tank into the intake manifold. No more leaks.

In his early testing phase he was using a two-blade prop. At 1500' above MSL he was indicating 190 mph, turning 6200 rpm. He now has a 3-bladed Performance prop and he can now indicate 190 mph turning only 5900 rpm. He says it is not only quieter but also nearly turbine smooth.

He said that cruising at 12,500 ft. and turning 5500 rpm his IAS was 160 mph. Fuel burn at that power setting is about 8.5 gal/hr., which is quite close to a 160 hp Lycoming's. He can use just about any gasoline, aviation or auto grade, with very little observable difference.

Ron's Long-EZ with its original O-235 weighed 825 lbs. empty, with no wheel pants, no starter, only minimum equipment, etc. The empty weight with the Mazda is 975 lbs., which includes wheel pants, starter, heavier paint, comparing favorably with other Long-EZs with Lycoming O-320 power.

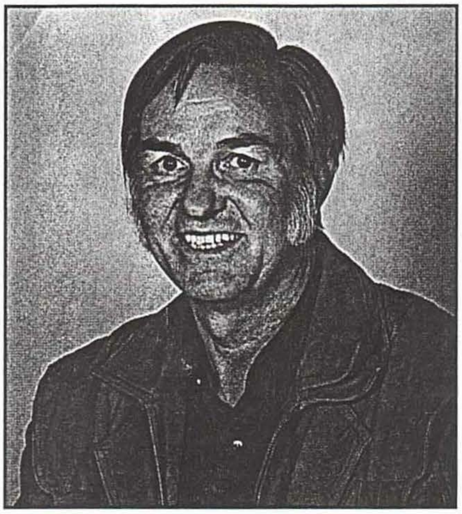
Ron says his total cost for the converted Mazda 13B engine, gear box, and oil tank is under $4500. His experience points the way for dependable, reasonably priced powerplants for a variety of aircraft now and in the future.

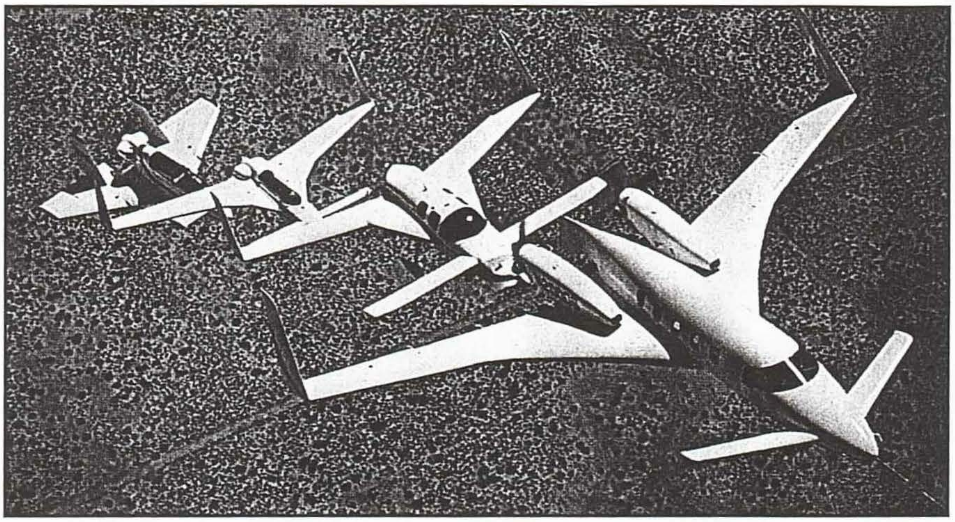
His next experiment with the 13B will be to turbocharge the engine. At the moment he has over 175 hours on the Mazda 13B, all nearly trouble free hours, he hastens to add. While the economics of an automotive type engine was the original stimulus for the 13B installation, he now is high on the reliability, smoothness and ruggedness of the Mazda. And, too, he always has strong kudos for Ross Aero's staff for their fine reduction drive and on-target advice.

So keep a sharp ear cocked at your next fly-in. Quite likely you'll be hearing more and more sounds that hum-m-m.

(Want more information on Ron's installations? Contact him at 316 Darrell Rd., Roanoke, TX 76262, 817/491-4646.) ◆

Homebuilders HALL OF FAME





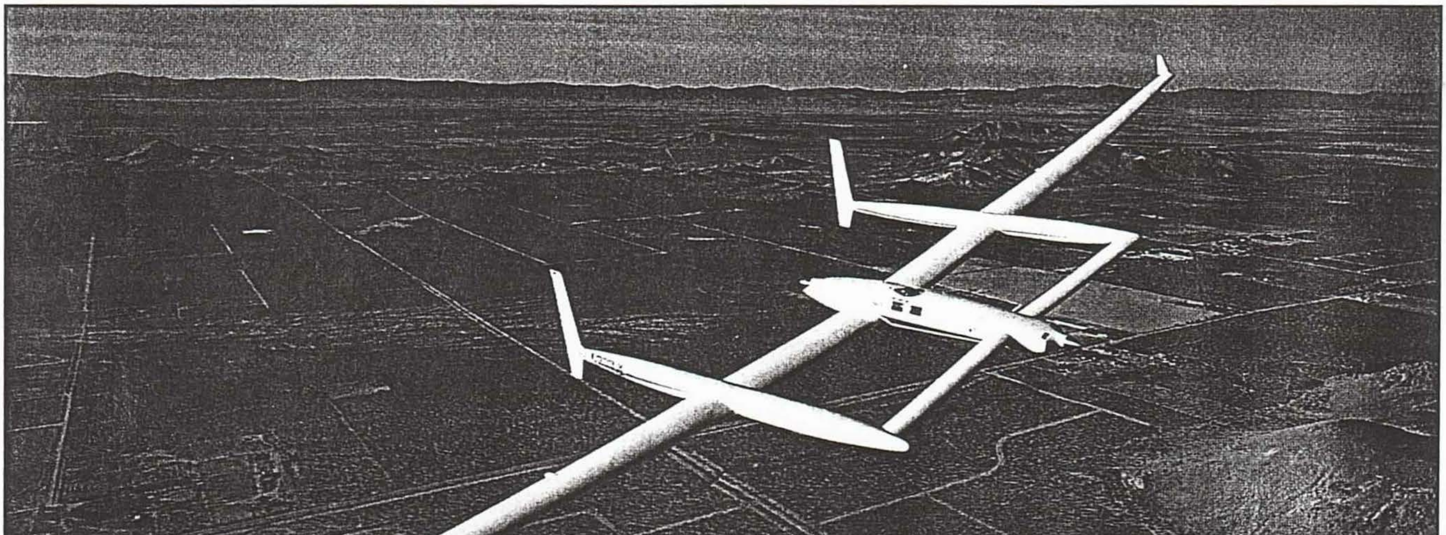
An echelon of Burt Rutan designs. From bottom to top: VariViggen, Long-EZ, Defiant and Starship.

BURT RUTAN

Aircraft homebuilding had been popular as a hobby literally since the days of the Wright brothers, but it was Burt Rutan who elevated the activity to the cutting edge of lightplane technology. The loaded canard he perfected on his VariViggen and VariEze/Long-EZ designs gave homebuilders a series of high performance aircraft without the susceptibility to stalls and spins of conventionally configured aircraft with higher wing loadings . . . and his "moldless" composite construction method made it easy and affordable for individual builders to create natural laminar flow airframes that provided greater performance for a given amount of power. VariEzes and Long-EZs were built in large numbers, and similarly configured spinoffs by other developers continue to be popular today.

The ultimate application of Burt's loaded canard and composite construction methods was the Voyager, purpose designed and purpose built to fly around the world non-stop without refueling. When Dick Rutan and Jeana Yeager set out on their historic and ultimately successful circumnavigation of the earth, they were aboard the only aircraft ever designed and built that was efficient enough to complete such a flight. Today, 12 years after the flight, that statement is still true.

Another highly significant contribution Burt made to the world of aircraft homebuilding was his simplified, step-by-step "cookbook" approach to aircraft building instructions, rather than traditional blueprints. It changed forever the way building instruction manuals were written and opened up the hobby to people who had not had



One for the history books — the Burt Rutan-designed Voyager.

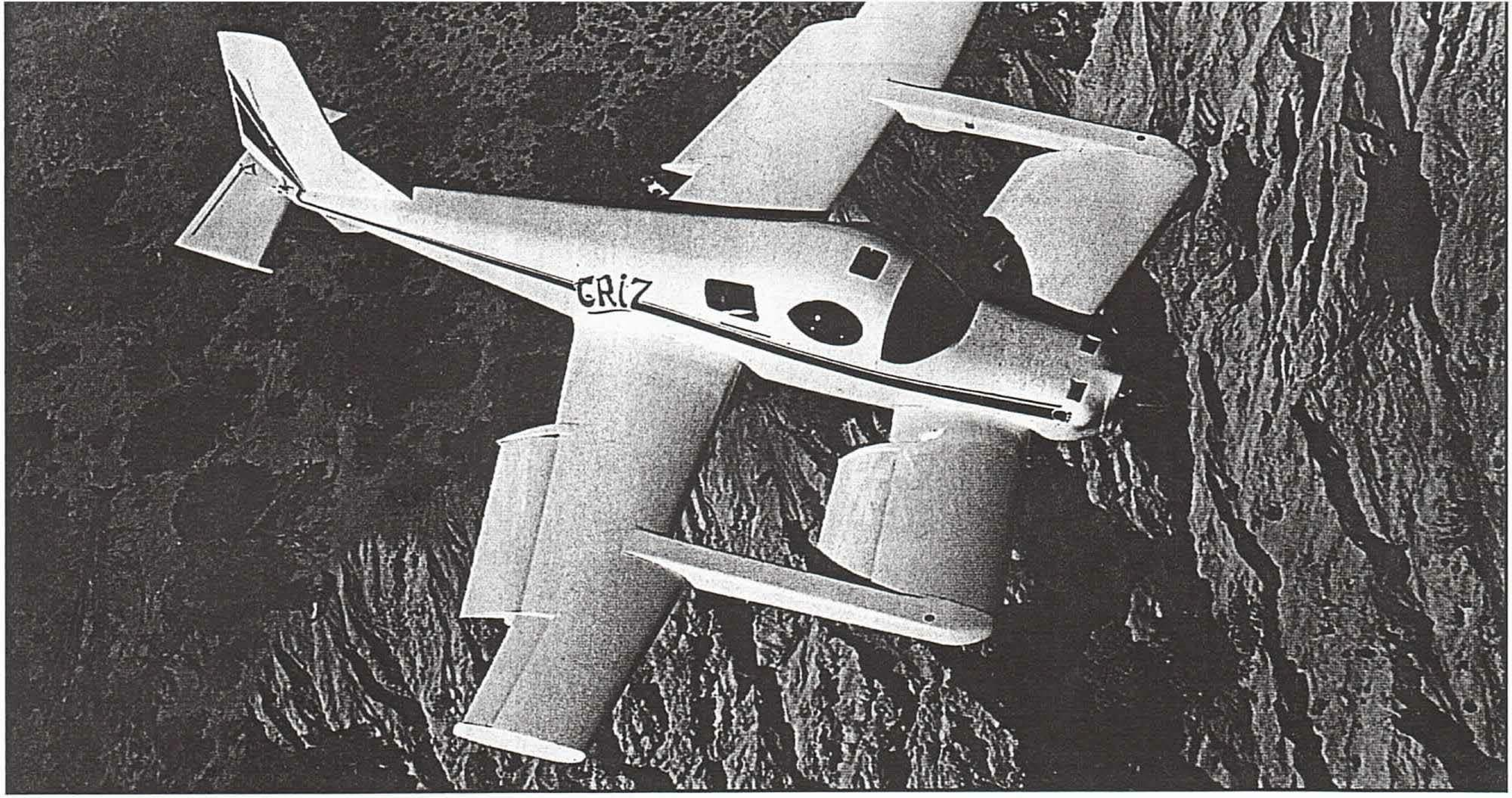
GOLDA COX

Klaus Savier, shown here in his ultra-efficient VariEze at the start of the 1999 Sun 100 air race, had an interesting flight to Florida from his home base at Santa Paula, CA. Climbing to 17,500 ft. to take advantage of a lower level jet stream with steady west to east winds averaging between 50 and 60 knots, he cruised non-stop to Memphis, TN in six hours and twenty-six minutes. His ground speed over the 1,450 nautical mile straightline distance averaged out to 224 knots (257.94 mph). The total fuel burn was 25 gallons, and the average fuel burn, from take-off to landing, including taxi and warmup/check-out, was 3.88 gph.

Tailwinds were, of course, a major factor, but the ability to take advantage of them is in part due to the large diameter propeller Klaus has designed and built for the airplane's non-turboed Cont. O-200. It allows him to climb to altitude quickly and continue to pull a lot of power - on this flight, 2,600 rpm at 15 inches of manifold pressure. True airspeed was 190 knots.

Klaus's VariEze is one of the most highly refined airplanes in the world, benefitting from extensive but subtle aerodynamic tweaks, his experimental propellers and, of course, his Light Speed Engineering Plasma capacitive discharge ignition system (check www. lsecorp.com for info) which automatically optimizes the spark timing for rpm, MP and altitude conditions to maximize fuel economy and power.

Klaus and his VariEze, N57LG, currently hold two FAI Class C-1.A world records: 1,000 and 2,000 km speed without payload (203.67 and 200.12 mph, respectively). They have been consistent CAFE and air race winners for years.



Burt Rutan's *Grizzly*, an R&D aircraft used to determine the feasibility of flaps on a canard aircraft.

technological training of any sort, which is the vast majority today.

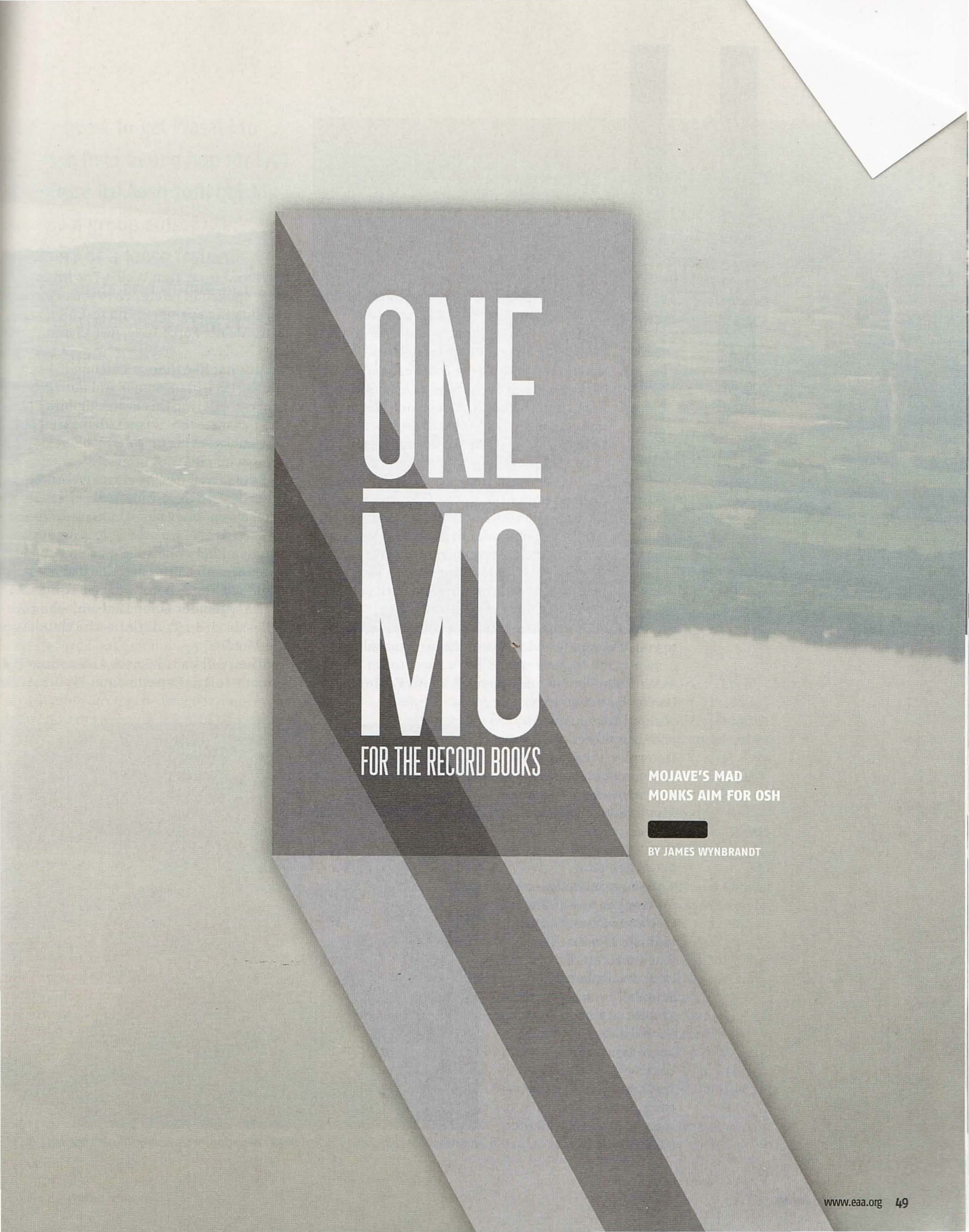
Burt Rutan was the first to use the experience and reputation he gained in the EAA world as a springboard to the more complex arena of aerospace design, development and manufacturing. Today, the company he heads is involved in some of the most daring, innovative aerospace concepts society is yet privileged to know about . . . and there is much more to come!

Klaus Savier gets the starter's flag

▶ ***Klaus Savier,*** AOPA 1253210, *won the Aircraft Spruce Copperstate Dash Air Race from Apple Valley Airport, California, to Coolidge Municipal Airport, Arizona. His VariEze averaged a speed of 188.53 knots over the 305-nautical-mile course.*

Five of the MoVenture aircraft:
Tango 2, Catbird, Glasair II, and

PHOTOGRAPHY BY **TYSON V.**



ONE MO

FOR THE RECORD BOOKS

MOJAVE'S MAD MONKS AIM FOR OSH

BY JAMES WYNBRANDT

HOW CAN A FORMULA ONE Air Racer with an 8-gallon fuel tank fly 1,500 nm nonstop? Elliot Seguin, EAA 841245, owner and builder of *Wasabi Siren*, asked himself that last spring after noting the absence of a sanctioned point-to-point speed record between Mojave, California (his home base), and Oshkosh, Wisconsin. The question was more than idle curiosity. "For me, Oshkosh is the center of the whole universe," Elliot said, recounting the visits he's made every year since age 8, when he camped under the wing of the family's Globe Swift with his father. He invokes the name of the founder of his employer, Scaled Composites, when explaining why finding an answer was so important. "As Burt [Rutan] says, 'It's not really an airplane until you've flown it to Oshkosh.'"

Whether or not that statement sounds reasonable to you, it resonates with lots of the airplane addicts drawn to the Mojave area. Elliot's quest to get *Wasabi* to Wittman field in one hop for EAA AirVenture Oshkosh 2014 quickly became a group enterprise: members of a loose fraternity of local pilots and homebuilders who call themselves "the Mad Monks Squadron."

ATTACKING THE AIR WITH A CLUB

The group, nameless until appearing in the credits of Disney's 2013 animated feature *Planes* (their aircraft dubbed the cartoon airplanes' sounds), coalesced around engineers at Scaled and other aerospace types who create cool aviation things at work and build and fly their own dream machines the rest of the time. The name is borrowed from Tom Wolf's *The Right Stuff,* spoken in reference to the era's ba rier-busting engineers and test pilots at Edwards Air Force Base, just 15 nm from Mojave.

"It's not like there's a members list," said Justin Gillen, owner and builder of Tango 2, offering this basic eligibility te You're a member "if you're hangared ou here and working on your airplane or o flying when it's 20 degrees."

Pilots from nearby airports—Antelo Valley, Palmdale, Lancaster, Tehachapi also belong. They share camaraderie a competitiveness, as they vie with each other and help one another to push per formance envelopes and do "bad ass stuff," as they call it. And, according to charter member Doug Dodson, who fli a Glasair II-S FT, "Elliot is the maddes the Monks."

Their *joie de vol* reached its apex at t annual Mojave Experimental Fly-In. At

Justin Gillen flew his Tango 2 with Jenn Whaley keeping an eye on Wasabi *in the passenger seat.*

Elliot's quest to get Wasabi to Wittman field in one hop for EAA AirVenture Oshkosh 2014 quickly became a group enterprise: members of a loose fraternity of local pilots and homebuilders who call themselves "the Mad Monks Squadron."

Elliot Seguin set a speed record for the Mojave to Oshkosh flight in Wasabi.

April 2014 event, five experimental aircraft attempted to break nine National Aeronautic Association records (a record number of record-breaking attempts in one event itself, according to organizers), and claimed seven new benchmarks, including the speed record over a 5,000 km closed circuit (211 mph) claimed by Zach Reeder, a Scaled project engineer, flying the legendary Rutan Catbird.

The fly-in's "great kinetic energy" inspired Elliot to consider getting his name in the record books on his way to EAA AirVenture 2014, he said, notwithstanding *Wasabi*'s half-hour endurance. He first sought the counsel of *Wasabi Siren*'s co-designer and co-builder, his girlfriend Jenn Whaley, a Scaled office manager. Designed primarily for racing and completed in 2013, Jenn said adapting *Wasabi* for long-distance flight "was always in the back of our minds."

"When we built the wings, we kept them open so we could modify them later if we wanted," she said. Later was now.

If he was going to attempt the flight, Elliot wanted someone on his wing. He asked fellow Monk and Scaled colleague Justin, EAA Lifetime 1017487, if he was interested in coming along with the Tango 2 (the *Tango Time Machine*). "Just to have eyes on him, to be the sag wagon," Justin recalled, using the bicycle touring term for a support vehicle. But few of even the most efficient experimental aircraft have a 1,465 nm range with reserves. Justin had chosen the 160-hp engine option (the lowest) for maximum fuel economy when building his Tango, but his tanks held only 58 gallons—not enough for the mission. If Elliott had to modify his airplane, so would Justin.

GO FOR THE MISSION

Endeavors like this don't stay quiet long in Mojave, and Elliot said news of the quixotic scheme "spread like wildfire." Even so, EAA AirVenture was barely three months away, and almost all of the pilots interested in participating would have to modify their aircraft for the flight—exactly the kind of challenge squadron members thrive on.

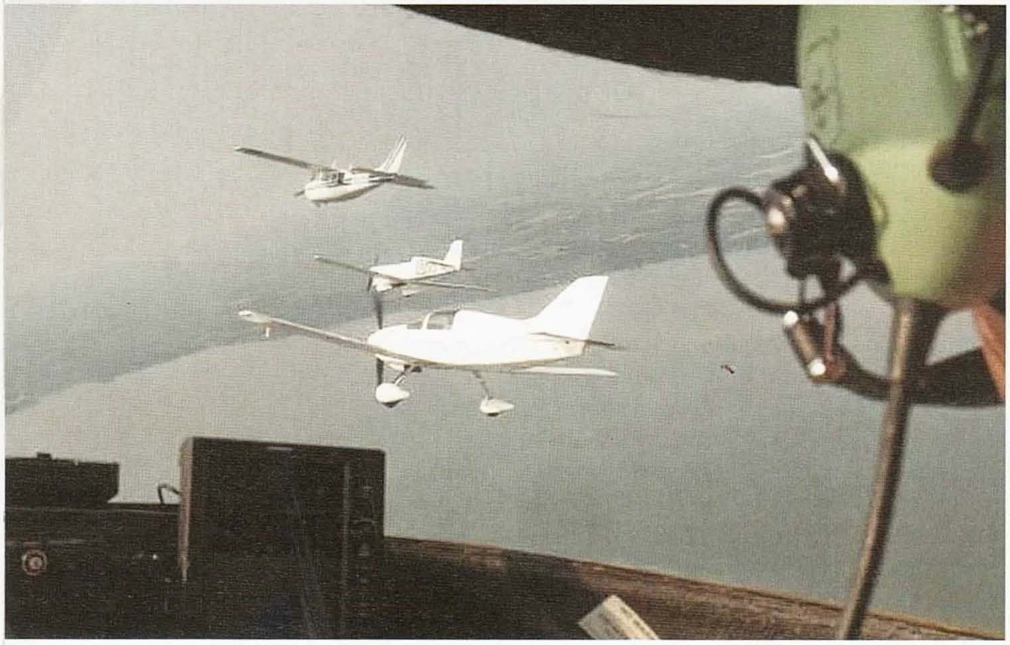
"Oshkosh is like the mecca for us all," said Zach, the Catbird rebuilder and caretaker (along with Jim Reed). Zach, EAA 777411, said the pilots involved enjoyed the challenge of extending their planes' performance. "It was kind of a neat goal for a lot of guys to push their airplanes," he said.

Brandon Cangiano, an aerospace engineer and Lancair Legacy builder and pilot, overheard talk of the mission at work one day. "I went back to my desk, crunched some numbers," he said. He figured with another 20 gallons of fuel onboard, he'd have the necessary reserves. Doug, the Glasair II pilot, rushed for "a sharper pencil to see if my plane can do it" when he got wind of the plan.

Dustin Riggs, who'd arrived in Mojave four years earlier with no pilot certificate and little more than vague dreams of getting involved in aviation, would fly Dick Rutan's globe-girdling Long-EZ, *Ol' Blue*, which Dustin, EAA 1106968, had meticulously rebuilt after becoming the legendary aviator's acolyte.

Word of the plan reached EAA headquarters, and soon the group had an invitation to make a group

To account for performance differences, MoVenture would have staggered departures, calculated for a rendezvous over the Mississippi River at La Crosse, Wisconsin, and a group arrival at Oshkosh during air show prime time. *Ol' Blue* would take off at 3 a.m.; *Wasabi*, the Tango, and the Glasair at 4 a.m.; and the Catbird and the Lancair at 5 a.m. They could count on good weather at departure, given the area's placid summer patterns, but had to consider the possibility of afternoon convective activity from rendezvous to destination. For final preparation, the MoVenturers underwent formation flight training together once modifications were complete; most lacked formation flying experience.



The MoVenturers underwent formation flight training together before flying to Oshkosh.

Justin Gillen, an engineer at Scaled Composites, built and flies the Tango 2.

MOMENT OF TRUTH

The group gathered on the ramp at Mojave airport the wee hours of July 28. *Ol' Blue* had a fuel pump problem on start-up and had to scrub its 3 a.m. dep ture. Elliot preflighted *Wasabi*. He'd had little slee endlessly reviewing checklists and contingencies i his head. "I was real nervous," he admitted. *Wasab* had never been this heavy for takeoff—20 percent its maximum standard weight—and more criticall the wingtip-to-wingtip tank design created the po bility that the fuel load could push the aircraft in a lateral direction that it might not have enough rud authority to counteract or braking action to stop before it departed the runway.

"I did a really slow power application, because P-factor would be the biggest exciter of directiona instability," Elliot said. Moments later he found hi self looking down at the runway lights from the ai turning on course, and thinking, "Holy smokes, we going to do this!"

They'd plotted individual GPS departure route separation until a join-up at 15,500 feet, but the pl collapsed almost immediately. "All the terrifying s happened in the first hour," Elliot said. Just miles the east, air mass thunderstorms filled the normal clear skies, and *Wasabi*, the Tango, and the Glasai dodged cells trying to stay VFR, lightning providi the only illumination. Justin had ADS-B aboard th Tango and kept the others informed of their relati positions. It wasn't until just before reaching Las Vegas, as the sun came over the horizon, that each cleared the weather. An hour later *Wa* and the Glasair had formed up on the Tango, Justin handling the radios for t flight of three. By then the Catbird anc Lancair were en route, and even *Ol' Bl* was finally airborne, Dustin having fix the balky pump, all in radio communic tion, despite the distance separating tl

The journey was also unfolding on Internet, as GPS Spot Trackers onboa the aircraft identified their positions f display on the MoVenture website. Fr the Catbird, serving as the mission's c mand platform, Rebecca took and e-mailed photos that were posted on t site in near real-time, while Niki mad hourly calls via satellite phone with tl arrival coordinator, Doug's wife, Gail, already at EAA AirVenture.

Aboard *Wasabi*, which unlike the others had no autopilot, Elliot kept th ball centered and tracked his fuel

PHOTOGRAPHY BY TYSON V. R

ustin Riggs meticulously rebuilt Dick Rutan's Long-EZ Ol' Blue.

nsumption, pumping 2 gallons from the ing into the header tank every 30 minutes. 15,500 feet, using about 50 hp from the 160- O-200 engine, *Wasabi* was burning some 4 llons per hour. Hours ticked by.

Nearing the rendezvous waypoint—the ississippi hidden beneath a solid underst—the two flights prepared for their in-up, with the Tango's ADS-B showing both nverging on the spot simultaneously. In his ancair, Brandon was diligently scanning his o'clock position. "Right in front of me were ree airplanes in a row, exactly where I xpected them to be," he said.

"We couldn't have asked for any less rama," said Jenn, who watched the Catbird nd the Lancair join the formation from ehind. "I can't even explain how weird it as. You're sitting in the airplane and thinkng, 'This is exactly what we briefed, and 's happening.'"

The Catbird took point position on the ight of the five-ship formation, and the egacy formed up on the left. Everyone hecked in with sufficient quantities of fuel nd oxygen. Chatter on their 122.75 common requency turned to the undercast. "We were debating how to get through, and this big opening just popped up in front of us," Niki said.

Doug, leading the formation, recalled nosing over into the hole, "and everything went from bright blue to green." For a desert dwelling group like the Monks, the experience was almost overwhelming. "To come out of the clouds, like this hole in the sky was made for us, and see green pastures and water was magical," Rebecca said.

Continuing onward, after nearly 10 hours in flight, their objective was almost in sight. "Elliot pointed it out first," Justin recalled. "I think his transmission was, 'Hey, is that Winnebago?'"

WHERE MOVENTURE AND AIRVENTURE MEET

Justin had been using his tail number, N131RG, to lead the flight, but now, switched to the air show controllers, he checked in using the group's mission name: MoVenture. They would perform a fly-by in formation down the flightline and then circle to land, but first they had to wait for a lull in the air show—their anticipation, and in some cases bladders, at the bursting point. Vectored to a

RUTAN LEGACY DAY

Burt Rutan, the visionary aircraft designer whose innovations made history and changed the aviation world, will be back at EAA AirVenture Oshkosh in 2015 to commemorate the 40th anniversary of his iconic VariEze aircraft. EAA has designated Tuesday, July 21, as Rutan Legacy Day honoring the legendary designer's return to Oshkosh, with all owners of Rutan-designed aircraft invited to participate.

Rutan's designs have been groundbreaking for more than 40 years, beginning with the VariViggen in the early 1970s through the concepts that became the SpaceShipOne and SpaceShipTwo vehicles that are launching the era of space tourism.

His use of canard wings and composite materials changed the look and efficiency of homebuilt aircraft, with more than 1,000 airplanes based on his designs now flying in the United States alone.

"There are few individuals in the history of aviation who can match Burt Rutan's imagination and accomplishments," said Jack Pelton, EAA chairman of the board. "His presentations are eagerly anticipated whenever he is in Oshkosh. Although he officially 'retired' several years ago, his innovative mind continues to push forward with new concepts and ideas that he'll share at EAA AirVenture in 2015."

Rutan is perhaps publicly known best for his SpaceShipOne design, which in 2004 won the $10 million Ansari XPRIZE as the first successful private spacecraft. He also designed the Voyager, which in 1986 became the first aircraft to fly around the world nonstop on a single tank of fuel. That accomplishment earned him, along with pilots Dick Rutan and Jeana Yeager, the Presidential Citizens Medal. Burt Rutan was also named to the National Aviation Hall of Fame in 1995 and EAA's Homebuilders Hall of Fame in 1998.

His VariEze aircraft first flew in May 1975, with the prototype causing a sensation at that year's EAA Oshkosh fly-in. That canard design evolved into other Rutan aircraft innovations, such as the Long-EZ, that are still being built today. Rutan's multitude of interests has also led him into successfully exploring space flight and into electric flight.

THE SKIGULL

After retiring in 2011, Burt Rutan did not embark on any new designs or builds and even wondered if he had the persistence to develop another aircraft. His highly innovative spirit would not stay still, however, as he then spent two years doing preliminary designs on what would become the SkiGull. Burt, working out of his garage in Coeur d'Alene, Idaho, claims this airplane will be his last project.

The SkiGull, which is being featured in the antennaFILMS documentary *Looking Up, Way Up: The Burt Rutan Story*, is described as a motorglider that can land on a variety of surfaces (water, snow, unimproved land, etc.) allowing access to remote areas like never before.

"Imagine an aircraft able to land in large swells near any ocean shoreline, ride the waves to the beach, from where you could hike in for lunch and gas," Burt said in a statement released by antennaFILMS. "Imagine also going to snow fields anywhere there is around 400 feet of relatively smooth snow, or to a dirt patch right at Puma Punku, or any part of the Amazon, including the tiny rivers that feed it. Imagine doing an eight-month exploration trip around the world without ever going to an airport."

One of Burt's longstanding policies is to not release any drawings or images of his designs until they fly, and accordingly he's not releasing any for SkiGull before test flight but has released some general teasers.

The design features a retractable ski system that will allow SkiGull to operate in most beach waves, large ocean crests, and very rough lake/river water. Without the skis it can operate from water, but it would then be severely limited to relatively smooth water, like other seaplanes.

It will be a two-place aircraft completely compatible with seawater so it will be made entirely with composites or titanium, and no aluminum.

Since the aircraft has not flown, Burt currently estimates it should have the range to fly from California to Hawaii without ferry tanks, and cruise at 170 knots.

"I know it sounds like Walter Mitty, but if it flies well, Tonya (Burt's wife) and I will explore the world with it, visiting the places you cannot easily get to any other way," he said.

Doug Dodson built a 15-gallon transfer tank so his Glasair II could make the nonstop trip to Oshkosh.

pair of successive holds, they watched smoke trails being painted in the sky while circling south of Wittman field. After half an hour, the air boss uttered the unforgettable words, "MoVenture, the airspace is yours." Justin aimed for the approach end of Runway 36, flanked by his Monk mates.

"It's an unreal experience," Brandon said, recalling the moment. "There aren't too many people who get to fly right down the air show centerline of Oshkosh during an air show. That's not for mortal men—that's for Yeager and Hoover. But for plain old guys from Mojave?"

The air boss invited them to make a second fly-by. With the MoVenture journey almost complete, a new adventure was about to begin, of basking in a heroes' welcome, of watching the daily air show from their honored parking spot on Boeing Plaza, and even posing for group photos in formation in the skies over EAA AirVenture. But for now, this final moment belonged to the man who inspired the implausible mission, and new NAA/FAI speed record holder

Justin had been using his tail number, N131RG, to lead the flight, but now, switched to the air show controllers, he checked in using the group's mission name: MoVenture.

[redacted]

(260.00 kmh) for the Mojave to Oshkosh flight, Elliot Seguin.

"When I rolled out on final for that low pass coming over the fence, I'm at race speed, hauling ass, knowing Jenn is in the airplane behind me," Elliot said. Suddenly a sight on the ground brought him back to his very first visit to Oshkosh. "I could see the spot where me and my dad had sat under the wing, eating cheese curds and watching the air show!" he said, his voice still filled with wonder. "Holy smokes!" EAA

James Wynbrandt, EAA 568059, is a multiengine, instrument-rated pilot who lives in New York City.

PHOTOGRAPHY BY TYSON V. RI

CALIFORNIA *COZY MK IV*

COZY 4518S BEGAN its life with the signing of the license agreement with Nat Puffer on May 25, 1994. The first test flight, consisting of four low approaches and a full-stop landing, took place on October 23, 2012, at Napa County Airport in Napa, California.

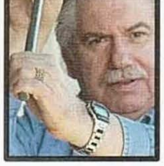
I purchased a Burt Rutan inspired kit from Aircraft Spruce and practiced the composite construction techniques. The aircraft was built per plans with one major exception: It's powered by a 1991 Mazda 13B fuel-injected, water-cooled, rotary engine driving a three-blade composite propeller, which I built. Tracy Crook, of Real World Solutions Inc., supplied the RD-1B gear reduction drive, the EC3 EFI ignition controller, and EM3 engine monitor. Instrumentation is VFR only, with a Garmin GTR 200 VHF comm/intercom, a Sandia STX 165 transponder, and a Dynon D1 Pocket Panel portable EFIS. I have logged almost 80 hours of flight time, including the FAA required 40 hours of test time.

The aircraft is a sweetheart to fly, with sporty performance and excellent visibility through the bubble canopy. Performance is typical of a canard-type aircraft, although I continue to experiment with different propellers to obtain a more efficient cruise speed.

I had the project evaluated by tech counselor Dwight F. Giles when most of the major parts were finished, and I spoke with C.J. Stephens, a flight advisor, prior to test flying. He was very helpful, as he flew the CAFE Foundation tests on a Cozy MK IV.

Always work on your aircraft project once a day, even if only for a few minutes. Projects fade and die easily when not worked on continuously until finished. *EAA*

John Schosanski, EAA 1076615; Napa, California
E-mail: *cozybldr@prodigy.net*



MIKE BUSCH
COMMENTARY / SAVVY AVIATOR

150-Year-Old Technology

Most of us are still flying (and driving) behind powerplant technology that dates from the 19th century

THE ORIGINAL FOUR-STROKE Otto-cycle internal-combustion engine was patented in 1862 by a Frenchman named Alphonse Beau de Rochas. More scientist than engineer, de Rochas never actually built an operational engine. The first working prototype was built by a German engineer named Nikolaus A. Otto, who was ultimately rewarded for his efforts by winning a gold medal at the Paris Exposition in 1867 and having the four-stroke cycle named after him.

The first practical Otto-cycle engines were built by another, better known German engineer named Gottlieb Daimler, who together with his lifelong business partner Wilhelm Maybach built a one-cylinder automobile engine in 1885 and a two-cylinder engine in the now-classic "V" configuration in 1889. Daimler died in 1900, and in 1926 his company Daimler Motors Corporation merged with Benz & Co.—founded by two-stroke engine pioneer Karl Benz—to create Daimler-Benz AG.

The basic power-generating component of an internal-combustion engine is the cylinder assembly, whose major components are a cylinder, a piston, and a pair of valves or ports (intake and exhaust). Each up or down movement of the piston within the cylinder is termed a "stroke."

SUCK, SQUEEZE, BANG, AND BLOW

An Otto-cycle engine employs an operating cycle composed of four strokes, with each successive stroke associated with a different phase of the cycle. The four phases are usually referred to as intake, compression, power, and exhaust—or colloquially, suck, squeeze, bang, and blow.

Suck: During the intake stroke, the piston moves away from the cylinder head wit the intake valve open, creating a partial vac- uum that sucks a combustible mixture (in our case, air containing atomized gasoline droplets) into the cylinder.

Squeeze: During the compression strok the piston moves toward the cylinder head with both valves closed, compressing the air-fuel charge into a much smaller volume, increasing its pressure and temperature, an making it more capable of combustion. The difference in volume of air-fuel charge between the start of the compression strok (piston all the way down) and the end of th compression stroke (piston all the way up) i termed the "compression ratio." Most aircraft engines have very conservative compression ratios (between 7-to-1 and 8.5-to-1); automotive engines usually have

THE FOUR-STROKE OTTO CYCLE

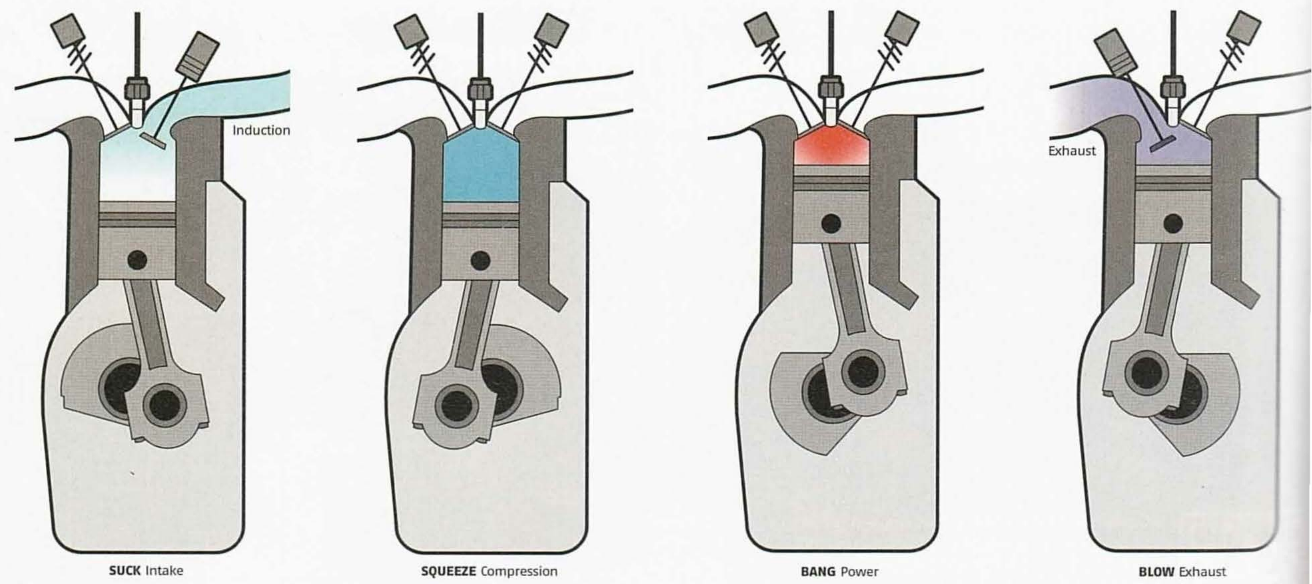


ILLUSTRATION BY CHRIS

compression ratios between 8-to-1 and 10-to-1, racing engines up to 12-to-1, and diesel engines 14-to-1 or more. The greater the compression ratio, the more efficient the engine at converting chemical energy into mechanical energy. (Piston aircraft engines aren't particularly efficient.)

Bang: During the power stroke, the air-fuel charge is ignited by an electrical spark (or by the heat of compression in diesel engines). Both valves remain closed, so the rapidly increasing pressure of the burning air-fuel charge drives the piston forcefully away from the cylinder head, converting chemical energy to mechanical energy. As the piston moves down in the cylinder and the volume of the air-fuel charge increases, its pressure and temperature decrease.

Blow: During the exhaust stroke, the piston moves toward the cylinder head with the exhaust valve open, allowing what remains of the spent air-fuel charge to exit the cylinder and be expelled through the exhaust system. Because piston aircraft engines are not very efficient, substantial energy remains in the exhaust gas as it exits the cylinder. In a normally aspirated engine, this energy is simply wasted; in a turbocharged engine, some of the energy is used to spin a compressor and raise the pressure of the engine's induction air, allowing the engine to produce more power (especially at altitude).

THE MORE, THE MERRIER, ER, SMOOTHER

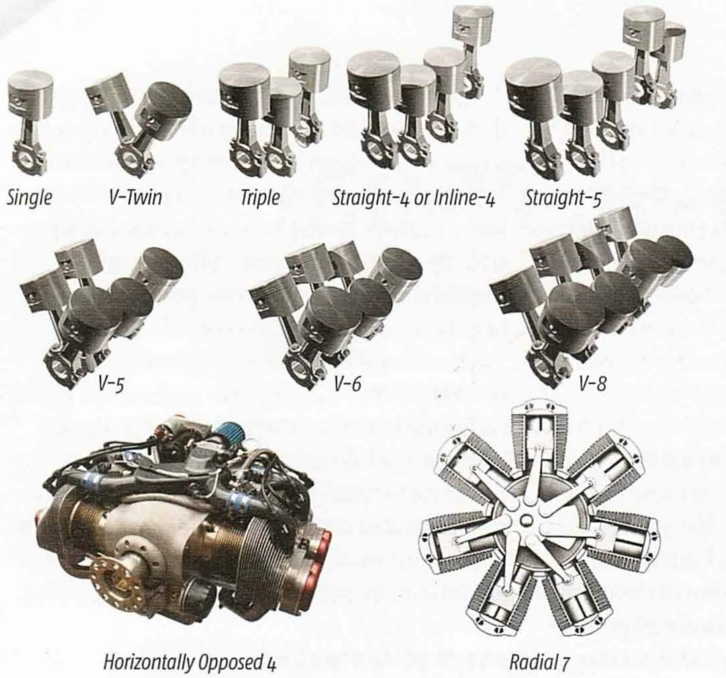
While the Otto cycle defines what's going on within a single-cylinder assembly, most piston engines have more than one cylinder. That's because a fundamental limitation of the Otto cycle is that it only produces power 25 percent of the time. Consequently, the one-cylinder Otto-cycle engines commonly used on lawn mowers and small motorcycles tend to leave a lot to be desired in the smoothness and vibration departments.

The obvious solution is to have four cylinders arranged so that one is always in its power stroke at any given time; this approach results in a much smoother-running engine with far less vibration. Even greater smoothness is possible by adding additional cylinders and sequencing them so that one power stroke begins before the previous one finishes.

Numerous cylinder arrangements have been tried. Most automotive engines use either in-line (straight) or V-type layouts (for compactness), while most aircraft engines use either horizontally opposed or radial layouts (for improved air cooling). The most common configurations in piston-powered GA engines are four or six cylinders horizontally opposed.

PRESSURE AND VOLUME

Although the four-stroke Otto cycle is conceptually simple, what actually takes place inside the cylinder during each cycle is remarkably complex, as are the critical



ENGINE LAYOUTS

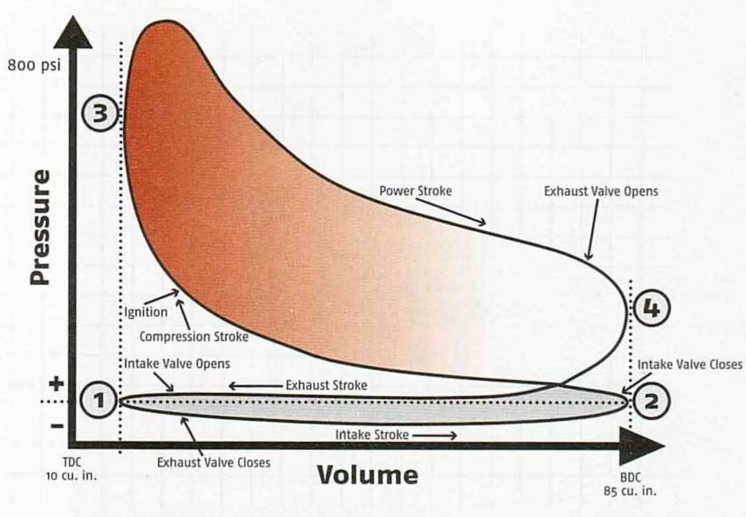
Otto-cycle engines commonly have four or more cylinders arranged so that at least one is in its power stroke at any given time.

timing relationships of piston position, pressure, temperature, valve opening and closing, and ignition. The more you understand about the combustion event and timing relationships, the better job you will be able to do of managing your powerplant, optimizing your power and mixture settings, and troubleshooting any engine problems that may arise. With that in mind, let's explore the Otto cycle a bit more deeply.

An excellent tool for visualizing what goes on during the Otto cycle is a "P-V diagram" that plots combustion chamber pressure and volume. Look at the figure below and let's work through the four strokes of the Otto cycle:

Suck: Beginning at point (1) on the diagram, the piston starts at the top of its travel ("top dead center" or TDC) and moves to the bottom of its travel ("bottom dead center" or BDC). The intake valve is fully open, the exhaust valve closes, and the descending piston creates suction that draws the air-fuel charge into the cylinder.

Squeeze: At point (2), the piston reverses direction and moves from BDC to TDC. The intake valve closes, and the air-fuel charge is compressed—for example, from a volume of 85 cubic inches to 10 cubic inches (a compression ratio of 8.5-to-1)—causing the pressure and temperature in the combustion chamber to rise accordingly. As the piston approaches TDC—typically 20 degrees to 24 degrees of crankshaft rotation before it gets there—the ignition system fires the spark plugs, and the air-fuel charge starts to burn, causing the pressure and temperature to increase even faster.



The P-V diagram plots pressure and volume of the Otto cycle.

Bang: At point (3), the piston reaches TDC and reverses direction again, moving toward BDC. Meantime, the combustion of the air-fuel charge accelerates, reaching a maximum pressure and temperature at about 15 degrees to 20 degrees of crankshaft rotation after TDC. This is the point of peak internal combustion pressure (ICP), which is typically 800 psi in a normally aspirated engir and as much as 1,000 psi in a turbocharge engine. This high pressure pushes the piston down toward BDC rather forcefully: 800 psi pressing on a 5-1/4-inch piston pr duces more than 17,000 pounds of force. A the piston descends and the air-fuel charg expands, its pressure and temperature drc considerably as chemical energy is converted to mechanical energy. Shortly befo the piston reaches BDC, the exhaust valve starts to open. Since the pressure in the cy inder is still considerably greater than outside ambient, exhaust gas starts flowin out the exhaust valve into the exhaust system in a process termed "blowdown."

Blow: At point (4), the piston reaches BDC and reverses direction once more, mc ing toward TDC. As the piston rises, it compresses the remaining fuel-air charge and forces it out the exhaust valve. Shortly before the piston reaches TDC, the intake valve starts to open, so that it can be fully open by the time the piston reaches point (and reverses direction to start the intake stroke. The brief period during which both intake and exhaust valves are open here is known as the "valve overlap interval."

Because of their low compression ratic spark-ignition piston aircraft engines are unusually inefficient as Otto-cycle engine go. They typically convert only about one-third of the fuel's chemical energy to mechanical energy, and waste about one-half of it out the exhaust and the remainin one-sixth in radiated energy from cylinde fins and oil cooler. The EPA-mandated move to unleaded avgas won't help this or bit. Diesel engines with their much highe compression ratios represent our best hop for more efficient piston aircraft engines i the future. *EAA*

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