ZERO THRUST GLIDE TESTING

The Development Of The First Practical, Full Scale, Test Method For Real Drag And Propulsive Efficiency On Propeller Airplanes

By Jack Norris and Andy Bauer

Drag and propulsive efficiency are the two most fundamental pieces of data in aeronautical engineering, and, most amazingly, for the nine decades since the Wrights mastered flight by successfully combining lift, control and power, these two fundamental facts have remained unreachable unknowns on propeller-driven airplanes! There has simply never been a practical, accurate, accessible test for real airframe drag and real propulsive efficiency on propeller-driven airplanes in flight.

Level flight speed/power tests give apparent drag, but that hides the real truth, the real propulsion losses, lumping them in with basic airframe drag and leaving them inseparable and indistinguishable. It turns out there is much to be learned and understood here.

Simply stated, despite billions in research, no one ever figured out how to devise an accurate, practical drag test on a propeller airplane, other than propellerless glides, which are rarely done. As a result, real drag and propulsive efficiency have remained unavailable. Propulsive efficiency is the ratio of the power (drag x true airspeed) that the airframe actually requires to the power that the engine must actually provide. For 90 years the aeronautical engineer has been forced to work around and assume the missing data with a patchwork of methods and assumptions . . . and the conclusions have not been correct. Indeed, aeronautical engineers tend to not recognize how basic and important, how downright bad propeller/engine propulsion efficiency can be, because they've never had a practical test or factual data.

In addition to propeller losses (nominally 80% efficiency), there can be a very negative interaction between the propeller and the airframe that can be better or worse than another 80% factor . . . 64% combined . . . depending on design and power applied, and cooling losses on top of that! Propulsion losses can be much bigger than recognized, particularly on the older and poorer aircraft designs.

Drag and propulsive efficiency are the prime unknowns because airplanes are flying machines that convert energy, fuel energy, into flight. Pounds of drag times trip distance in feet equals "foot pounds" of mechanical energy, BTU's of fuel energy required, considering the all important (in)efficiency of the propulsive system: propeller efficiency, propeller/airframe interference and cooling drag. (There are 778.26 foot pounds of mechanical energy per BTU, nominally 19,000 BTU/lbs. in avgas.)

Once you have a real test and start seeing the real truth of the matter, you find airplane drag can be better (lower) than has been realized, but propulsive efficiency can be much lower than has been realized. Happily, it is much better on the best new designs today. Overall engine thermal efficiency, combined with propulsive efficiency is a technological disaster, a gaping pit of inefficiency crying for appropriate attention in order to provide us with an improvement in the next century, only a nominal 18 to 24%.

Once you have a way to get to the real truths of the matter through practical, accurate testing, the whole game changes for pilots and design engineers alike. Once it's possible to put a real drag curve in front of the pilot and that 18% overall efficiency number, the pilot begins to realize that it's worth paying attention, worth learning the thinking person's way of flying an airplane efficiently and not fly on the too vertical part of the drag curve where the payoff in speed vs. cost is poor - because fuel use is already 4 or 5 times the real energy requirement!

Put an 18 to 24% efficiency number before the airplane and engine engineers and they immediately understand they have their marching orders for now and for flight in the next century as fuel becomes more scarce and costly . . . and real test data gives them the insight to get there, starting now. We deserve better!

Amazingly, our most competent field, aeronautical engineering, has given us personal flight, near million pound transports for business men and grandmothers alike, supersonic flight, fly by wire controls, satellite

Jack Norris' 1947 Luscombe 8E . . . used for the first zero thrust experiments.

weather and navigation and has taken us to the moon and back, but has suffered the indignity of the lack of the most fundamental of tests to check and refine the most basic calculations. As a result, our insight has been hampered. That sick 18% number I'll explore further for you shortly is ample evidence of that. Jets are great, but at max range, a 900,000 pound plus 747 uses over 360,000 pounds of fuel. That's almost seven 8,000 gallon double tank truck loads, just about a 19.5 foot cube per flight!

We've all had the great gift of being born at the right time, in the right century, in the greatest country ever. I've been most fortunate to have the great fun of working on some of our most interesting technology; in flight, jets, space and other diverse fields as engineer, entrepreneur, business founder, executive and high tech management consultant . . . but flight was always my fun, my avocation. Technology can be great fun, but there are also days with huge problems and plenty of pressure. I bought my now Classic 1947 Luscombe 8E at Christmas 1950 for $1,225, using my winnings in model airplane competition. I was a senior in engineering school at Ohio State at the time. The Luscombe has always been my simple, reliable, no demand R&R escape vehicle. No matter how tough and burdensome the technical or business problems had become in the crunches, an hour in the Luscombe rendered the week's oppressive problem a mere detail to be solved as a challenge. Perspective is a wonderful thing, and there's nothing like flight to get perspective on the world.

As a kid of 15, I had to solve the graveyard spiral dive and crash problem before I could succeed and win against the really high performance free flight models that all the big kids were building. Flight and how it really works became a lifelong interest.

By 1982 I had a lifetime of experience that included jet servo flight control packages that really did fail-safe . . . absolutely never failed, because there was no further backup. Over 100 of my own spacecraft rocket control products are on the spacecraft in the central hall of the National Air and Space Museum in Washington. With more time, financial independence and fewer professional and technical headaches, I looked at my classic R&R vehicle and decided to quit flying it like an unaware driver and, as a fun project, figure out the real logic, how it really worked . . . to pick up professionally where I had left off as a modeler at age 21.

Boy, did I get a fast education and a rude awakening! I found essentially nobody could give me a proper education on flight mechanics, the logic of flight. The best pilots didn't have a clue, the proficient engineers didn't know what to explain or how to do it, lacking the grasp of what a pilot needed to know. I was quickly into **Aerodynamics for Naval Aviators**, a great reference, putting together my own logic of flight. There is a beautiful logic and it all comes out so amazingly simple and interesting that everyone should know about it.

I found I could not test my Luscombe to get a real drag curve, real propulsive efficiency. Propulsive efficiency and accurate drag calculations were an empty hope based on multiple assumptions. The classic tome on drag by Hoerner targeted an 80% propulsive efficiency (based on an 80% efficiency of a prop in a free stream), then went through a calculation drill to make the sum of all the parts match that number. I wasn't sure I believed that, after learning time and again that assumptions are not the way to a sound bottom line in engineering. If you don't have a test, you are at big risk!

Real airplanes have small to gross leaks at control surfaces and skin corrugations, major cooling drag, rivets, antennae, angular joints, less than wonderful sheet metal work, pumping losses roaring from holes at the tail . . . to leaking, low pressure cockpits, doors and canopies. Small tractor propellers on less than sleek planes try pulling themselves forward by their bootstraps, blowing back on the airframe while attempting to thrust themselves forward. Pushers have garbage in, if not garbage out. After a lifetime in the engineering profession, I didn't need anyone to tell me calculations or scale wind tunnel tests were not going to yield the truth on all that real world complexity.

Refurbishing my Luscombe prop, I threw it on the granite inspection plate, after hours, at one of my consulting client's plants. A layout check and a little trig produced the shocking fact that it was almost within .1 degree of perfect helical pitch outboard of the structural inboard segment. I was told McCauley shop tolerance is only .2 degrees. Impressive, but I would learn that you really don't want pure helical pitch. You want to match the slowing layered airflow at the nose (or rear).

Occasionally getting my hands on a copy of **Soaring** magazine, I knew of the technically elegant glide testing work that the soaring fraternity had been doing for years to evaluate drag and performance. The basic physics of gliding flight is that the potential energy of height is converted to the kinetic energy and the power requirement of the flight path, an elegant direct tap on the basic physics. They measure the conversion as shown below. Richard Johnson, many times national soaring champion, had raised drag and performance testing to an art form. His March 1983 evaluation of the ASW 22 shows incisive bumps on the drag curve as laminar flow converts locally to turbulent! Real world testing doesn't get better than that.

Flight path power = vertical sink power

Drag# x TAS = GW# x sink rate

$$\text{Drag\#} = \text{GW\#} \times \frac{\text{sink rate (ft/sec)}}{\text{TAS (ft/sec)}}$$

The light bulb lit. I could calculate an rpm for that accurate prop for a near zero thrust, minus 4 degree angle of attack, for several true airspeeds and go glide test the Luscombe with (almost) no prop there. Viola! In one weekend I had a moderately good ball park drag curve, a ton on insight . . . and conclusions that never basically changed over 10 years of ever more refined work . . . that did not agree with Hoerner's book at all!

Look closely and you will see the wire that rubs on the back of the prop hub to trigger the zero thrust light.

The drag curve of the classic high aspect ratio Luscombe was surprisingly low, but that calculated out to ridiculously low horsepower requirements, which said the propulsive efficiency was terrible, nominally 60% or a few percent above, worse if I would have added tight, closable cowl flaps, cut out the cooling drag and removed that propulsive penalty for the airframe. Now hold that grasp for a moment before we proceed with the development of Zero Thrust Glide Testing and I'll go back and tie in that 18% overall efficiency number I know you're curious about.

Separately, I was playing with cruise control, the logic of flight, a thinking person's way to fly . . . real, intriguing, easy smarts for the pilot. The high aspect ratio Luscombe can be made to go faster by burning extra fuel, but with that long wing, by design, it's really a 100 mph cruiser. Purposely flying at a calibrated 85 IAS, 100 TAS at 8,500 feet, hot, 10,500 density altitude, 2,280 rpm, leaned at low power (45 hp) for max economy, I can fly non-stop from LA to McCall, Idaho or Rick Springs, Wyoming on my Deluxe 8E's 30 gallons. That's only 3-3/4 gph vs. the 5 to 5-1/2 gph that the manual says. That's 26.66 mpg, but still at 100 mph TAS.

The fuel burn sounds way too low, doesn't it? People tend not to believe such a low fuel burn at the Luscombe's 100 TAS. Here's the shocker. Using that thinking person's way to fly brings the overall efficiency way up to a miserable 18.2% That low compression heat engine without spark advance, with a big cooling load and dumping exhaust at nearly 2,000 degrees has a nominal 30% thermal efficiency. Multiply that by a nominal 60% propulsive efficiency and you get a terrible 18% overall (only 24% at 80%). Energy calculations yield a precise 18.2% as an independent overall check that our test data is correct.

Knowing that number, incidentally, allows me to figure out that it takes just about one gallon of fuel to hoist a 1,400 pound gross weight Luscombe to 10,000 feet, an insight I'd never been able to nail down before. The game then becomes recovering as much as possible of it on a letdown when the engine is throttled, thus even more inefficient . . . and you can't recover more than the 18%! The 82% was lost heating the atmosphere. Gone.

Having fallen into being the rare expert on the subject of intelligent flight, on a chance visit I fell into being the Technical Director on the Voyager World Flight in 1986 and ended up writing the official book, log, analysis and explanation of the flight for the National Archives, an interesting, separate story. Copies are still available, if you'd like to see the real inside facts on that great feat (see sidebar).

There are limiting thermodynamics problems, but bet on the fact that in the next century the game will be better than 18 to 24%.

Back to Zero Thrust Glide Testing. As an engineer, I knew I was onto the right track for some real breakthrough progress on testing for drag, cooling and propulsive efficiency, but I also recognized I was a rank amateur in the very sophisticated analytical capability that the great aeros have developed and specialize in. By great good fortune, a chance meeting in a class at Ohio State had developed into a lifelong friendship with Dr. Andy Bauer, also a modeler from those youthful days of the 1940's. Andy was a fully competent aero at Douglas Long Beach, had a Master of Science degree from Ohio State and a doctorate from Stanford. Rare in this jet age, as a modeler he could calculate a propeller with great insight and had just completed a test program on flow around bodies, both blunt and refined. Putting our two lifetimes of experience together, we had the potential for some real progress.

Andy quickly educated me to the fact that though the air had to speed up to get around my fuselage, the Luscombe's relatively blunt cowl and the proximate windshield had the prop flying in a layered bed of air significantly slower than flight speed (ultimately about 8.5% slower). We quickly teamed up and soon Andy had me set up for a more sophisticated glide test that took into consideration that slowdown of the air. We would lower the calculated Zero Thrust rpm and increase the test drag somewhat for a more refined answer with ever better insight and accuracy over the succeeding 7 years. We both saw we were working on the most fundamental testing and basic data gap in flight, and it became a multi-year part time challenge effort, with ever more sophisticated analysis and test insight into the problem.

Along the way, we learned of other, often wild efforts to find a test solution for "real" drag. Bill Lear did glide tests on his Lear Star with both recips off and feathered! That was nothing compared to the early efforts at Northrop on the then secret Black Widow. Max Stanley, now a good friend and fellow QB, at the request of head aero Dr. Bill Sears, had tried vertical with both engines off and the props feathered! Max, the final test pilot of the original Northrop flying wings, chuckled at the classic simplicity, the elegance of our sailplane-like final solution: using a simple modeler's zero thrust switch.

August Raspet, Dick Johnson' professor and mentor at Mississippi State, and George Lambros came closest in 1954 with propellerless glide tests of a Bellanca Cruisair towed to 12,000 feet with the cooling ducts sealed and unsealed. They got excellent insight, despite being harried by dead stick landings at the end of every test. Seeing terrible propulsive efficiency (58%), as we did, comparing the sealed duct glides with level flight speed/power tests, they were more shy than they should have been because they were actually onto the real truth of the matter that is still not widely understood.

Our mutual testing, confirming each other by independent arm's length work, gives the confirmation, the corroboration that good science demands. Raspet also tested the Cessna 120 and reported a 60% propulsive efficiency; and Jack Cox, right on the ball, supplied us with a copy of the testing of Steve Wittman's short wing Tailwind, reported in the October 1956 issue of the **EAA's Experimenter**. It showed the typical drop off in propulsive efficiency as power was increased as our Luscombe testing did.

By 1989, with time off for the Voyager effort, we had the best data that sophisticated analysis and parallel testing could produce. Andy is a jewel! We offered a paper for the January 1990 Reno AIAA Conference and were accepted. Even after 7 years of work, I panicked a bit, however. The original objective was a free standing, independent test, not dependent on analysis. With dues fully paid, we now had wonderful insight into every minute aspect of the problem, with Andy's excellent work, but we were also off the original track . . . encumbered, inhibited from the creative spark that was needed for a free-standing test after 90 years of aviation history.

Recognizing that, I backed off, put the minutiae out of mind, let the real problem . . . how to physically do a Zero Thrust Glide Test . . . gurgle around in my brain, and my subconscious spit out the answer like the faucet was suddenly opened. I laughed. It was a classically simple answer, but one that only a pilot of a simple plane would see, and only if he had all the necessary objectives and questions in his head. Understanding that there is a problem is necessary to invent a solution. It's indeed true: invention is 90% prior perspiration, then 10% inspiration.

When you go to prop a small plane, you yank on the prop to be absolutely sure the guy in the cockpit really has the brakes on. The prop goes "klunk" because there is a small axial clearance in the thrust bearings, about .010" to .020". The same small klunk happens in flight on loose engines when you transition from either thrust or drag. An engineer knows that in most cases there are no bevel gears and no pressure bias, and a rotating shaft is essentially, absolutely friction free in the axial direction . . . **so that zero thrust can be detected!** (There would be one final challenge to be encountered and solved in our EAA/CAFE program.)

With a grasp of dynamics, you know you do not want a micro switch, which is a rat's nest of vibration problems, as a sensor. You know intuitively that a simple, light, short, stiff piece of 1/16" model airplane music wire set up as an electrical switch to kiss or miss the back of the propeller hub makes the perfect vibration proof sensor. Stiff and light, it will have a very high natural frequency of vibration, be completely invulnerable to the low engine frequencies. Mounting it on a phenolic block for insulation on the front of the crankcase allows you to use a simple flashlight bulb on the instrument panel as an output to visually indicate when zero thrust was occurring.

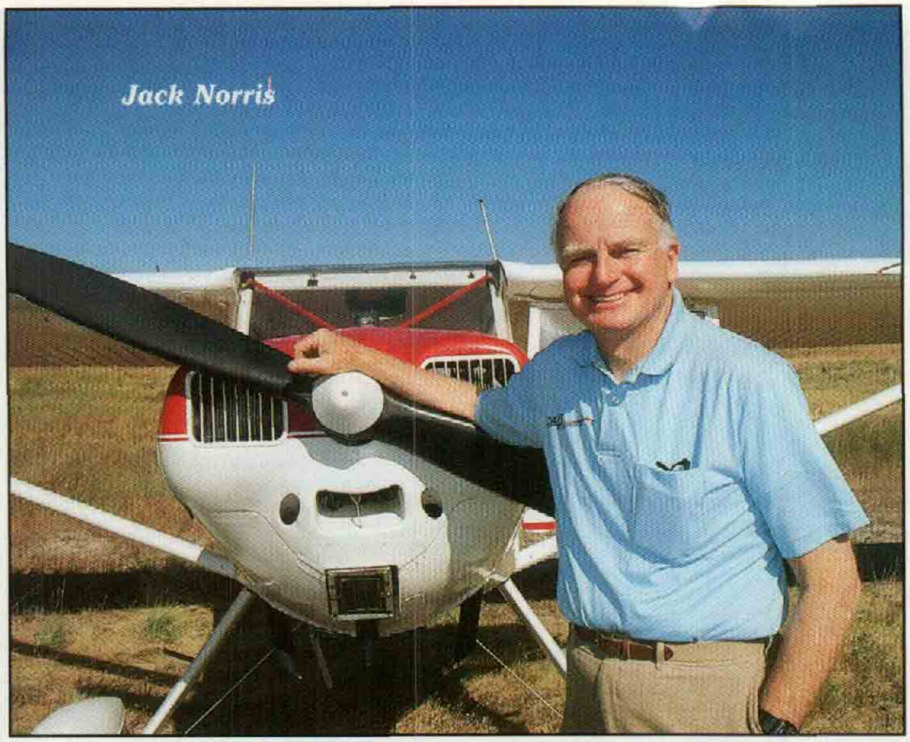
To accomplish accurate Zero Thrust Glide Testing, you simply need to "fly" the prop accurately at zero thrust, with no axial friction, no bias, using a vibration proof sensor. Nose down or nose up, the weight of the prop/crank will try to slide forward or back, but that one very accurately definable bias can be easily and accurately handled in either of two separate ways.

Method 1: Fixed Pitch Prop - With a simple level in the cockpit (prop vertical), you can glide at the speed where the crank is perfectly level and find the accurate ratio of rpm/TAS for zero thrust. Yes, there is an accurate ratio and it stays accurate. Of interest, that's 14.94 rpm/mph TAS on my Luscombe with a 71" x 51" cruise prop, just under 1,500 rpm at 100 mph; and precisely 747 at 50 mph, an easy to remember mnemonic. That ratio can be used accurately (a digital TAC is handy, ideal) at any true airspeed, any altitude, and there is no slope angle correction with that method. In high speed glides, at a lower angle of attack, a precise analytical investigation will show less wing flow circulation, a tad less slowing of the airstream at the prop disc (high wing), a tad of prop drag amounting to a 1% or less erroneously high drag. Pros have to work smart to get to 1% data but you can apply that small correction if you decide to get that precise.

Method 2: Constant Speed or Fixed Pitch Prop - With Method 2, temporarily ignoring the "downhill" prop/crank weight error, you simply go out and do glide tests holding the power or rpm at the point where you just get a "false" zero thrust indication. False by the inclination error caused by the prop crank weight x the sine of the inclination angle. The bias error on the Luscombe is 0 pounds to 6 pounds excess indicated drag with a 47 pound prop/crank. The inclination angle can be measured with an inclinometer or calculated. The glide angles are less than you think.

The prop has always been a huge problem . . . a big power absorbing windmill, a thruster, an unsolved road block preventing drag testing of the real airframe, interference, warts, leaks, et al.

Dr. Thomas M. Weeks, editor of the **AIAA Journal of Aircraft**, recognized the method as the basic, significant piece of progress that it is



Jack Norris

and can be and requested that we prepare it for publication in the prestigious AIAA Journal of Aircraft. Now, not hurried, we carefully reran all tests, refined the test for publication, went through peer review and published in in the May-June 1993 issue.

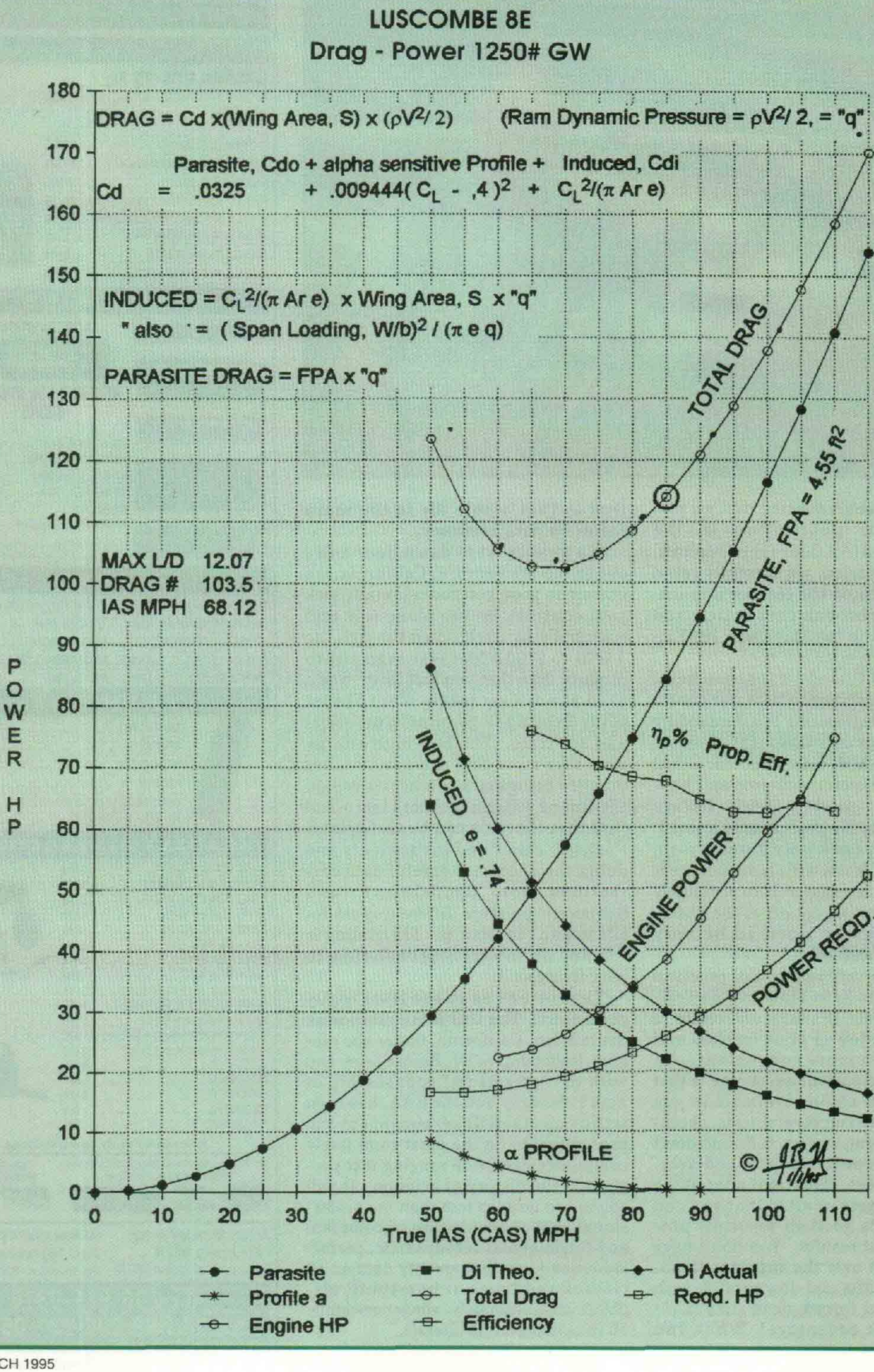
No "cold fusion" nonsense here. We didn't rush out to beat our chests in public. Engineering is a demanding business that cuts down the promoters. We checked, cross checked, talked with other experienced pros and honored their good insights before publishing in the professional journal. The Physics Book only knows truth, and to rush forth with mouth in gear before brain is engaged is to absolutely guarantee getting cut off at the knees. Good engineers learn to be very straight, honest folks.

There are very important, practical advantages to Zero Thrust Glide Testing. Obviously, it's safer and easier to do than the towed glide method and much, much more convenient. An even more important advantage is that you have the engine available so you can climb and run several tests, checking and proving when you do and don't have good repeatable data, and averaging the best. The final advantage and the biggest of all is that you can go find really good air for really professional test results. You don't have to do it right over the airport with potential updrafts and downdrafts, with a subsequent forced, dead stick landing. A huge advantage! **What you find is that stable air is the main factor in data accuracy.**

We found that at dawn, four miles out to sea off Ventura, California, we had air so good you could literally lock your controls, let the plane sink and essentially fly itself down through the 3,000 to 2,000 feet test segment to produce data that you just knew was a good as any ever taken. Zero Thrust Glide Testing is genuinely practical and accurate. The fast high energy tests take more skill and practice, but practice brings competence. I've had the fun of watching others learn and find that they too can be test pilots! Precisely calibrated instruments and doing the necessary careful data corrections for temperature and barometric pressure differences are really where the labor is. The gliding is fun and an interesting challenge to your flying skill.

That brings us to the final really good news. The CAFE Foundation in Santa Rosa, California, under the creative leadership of Dr. Brien Seeley and with the "go gettum" sponsorship of Tom Poberezny and the EAA, has been setting up and refining equipment and procedures to do the most completely comprehensive, wide ranging test program in the history of aviation. It will amount to nothing less than the professional caliber acquisition of complete and fundamental aerodynamic, performance and handling quality data on all classes and types of homebuilt airplanes and, ultimately, almost certainly, all the other private aircraft.

FLYING THE THINKING PILOT'S WAY



Picture - worth a thousand words! The intelligent way to fly an airplane is at low drag, which is at low indicated airspeed. Then go high to get free true airspeed, get your engine wide open and lean for maximum thermal efficiency, all of which maximizes miles per gallon. Look at the graph: at 85 mph IAS, at high altitude and the engine at maximum efficiency, I have only 82% of the drag I would have at 100 mph. This is at a favorable "knee" in the propulsive efficiency line, which is terrible at 100 mph. This is how I go 800 miles nonstop in my Luscombe 8E on cheap auto gas, beating the socks off the guys trying to go fast down low and stopping in the summer heat to buy $2.00 per gallon 100 LL. Work yourself through the "short course" in aero engineering contained in this graph **and fly smarter!**

The standard leaning "lazy J" total drag curve results from an essentially constant parasite drag coefficient, producing a (V2) parasite drag curve that swoops up as speed increases (twice as fast, 4 times the drag), and a highly variable induced drag coefficient, dependent on CL2, that produces exactly the opposite effect, a (1/V2) curve that swoops down as speed increases (twice as fast, 1/4 the induced drag). Notice the combined total drag curve goes vertical very rapidly. **It's just not smart to fly way up on the vertical part of the drag curve!**

A significant part of the parasite drag is the profile drag of the wetted wing surfaces. A small part of that is angle of attack, which we've been able to separate out here, due to the sensitivity of the method and extremely good test conditions found out over the ocean at dawn. As shown here, it acts like induced drag, a function of CL2, and is usually lumped in with induced drag rather than being shown separately.

These parts of the drag coefficient are combined, then multiplied by the wing area and the ram dynamic pressure, "q," measured by your pitot tube. That produces the J-shaped total drag curve . . . in pounds vs. indicated airspeed, or its components which are shown here so you can see and grasp the whole subject. **Fly low indicated airspeed . . . high!**

Since the constant parasite drag coefficient is multiplied by the wing area, which varies from plane to plane, it is not proper to compare drag coefficients of two planes. However, Cdo times the wing area gives a quasi equivalent flat plate area that is a legitimate comparison between planes that is easy to grasp. Flat plate area does **not** include induced drag.

In our test of the classic Luscombe, we found an airspeed system that lied, which is not at all unusual, a 4.55 ft.2 flat plate area and an Oswald factor, e, of .74, a simple fudge factor to get Prandtl's classic theoretical formula for the induced drag coefficient up to its real value. ($Cdi = CL2/\pi\ Ar\ e$, where Ar is the aspect ratio, span/average chord)

Pounds of drag multiplied by true airspeed in feet per second gives foot pounds per second, the units of power (550 foot pounds per second per horsepower), so a power required curve can be calculated directly once you have a drag curve. If you run a standard speed-power test and curve for the plane, you can plot both the power required and the actual power input curves, and, dividing, get the propulsive efficiency for the plane at various speeds. **The great insight you will gain is that the Luscombe, like most of the planes of its day, has a poor and degrading propulsive efficiency.** August Raspet found that out in the '50s, but no one seems to have caught on. The Luscombe and its contemporaries are speed limited as much by poor propulsive efficiency as by drag!

Notice how the engine horsepower curve increases noticeably faster than the power required curve, due to the falling propulsive efficiency. Also notice that the engine power curve did not prove to be smooth like the drag curves. With miles per gallon dependent on indicated air speed, low drag and high propulsive efficiency, do you see why I fly at only 85 mph indicated airspeed, at low drag, at the favorable knee in the efficiency curve, but up high at 100+ true airspeed with my engine wide open and leaned for maximum efficiency to fly 800 miles from LA to Idaho on only 30 gallons of fuel? For a given gross weight, drag (thus miles per gallon) is constant at constant indicated airspeed at any altitude, but power increases as true airspeed increases, so I fly up high at about 45 horsepower . . . flying faster, not hurting the miles per gallon and actually gaining engine efficiency by running wide open.

Our best new homebuilts, a new leading edge of flight, will prove far superior. Next month we'll show you the great insight that comes from directly comparing an RV-6 and a Luscombe . . . lower drag, better propulsive efficiency, better miles per gallon, faster . . . win, win, win, win!

That's where the story picks up next month, and we'll even tell you some of the problems and challenges, some of the very interesting insights that are beginning to emerge. The CAFE group is a remarkable fortuitous gathering of the right people, each just about perfect for his part of the task. The EAA chipped in some serious money to equip the test program, but without the unique team of volunteers, you couldn't do what's happening in Santa Rosa without aerospace megabucks.

What will come out is scientific proof that homebuilt airplanes are the new leading edge of flight. No more of this 60% propulsive efficiency nonsense. What we will see is remarkably lower drag, far better efficiency than the previous generation of aircraft . . . just artistically, aerodynamically superior aircraft. The 21st. Century is upon us and as in 1903, homebuilt aircraft are at the leading edge. It was homebuilders, former modelers who did the Voyager World Flight, the most recent "mission impossible" major milestone aviation feat. What a great time to live, fly and appreciate! ◆

VOYAGER

The Voyager, The Last Great First, was a stellar product of the homebuilt movement, the first homebuilt major milestone since the Wright Flyer. Voyager was just like a home-grown Moon program, only done with a very small, tight group of very competent people . . . with no bucks, rather than the aerospace industry standard of thousands with billions. The work was every bit as good as the Moon program. I know because I was right in the middle of both of them! The Voyager's accomplishment could not have been easier than Apollo because it came 17 years later. It couldn't happen until people were smart enough, sophisticated enough to do it. Burt Rutan used the best new structural materials to the max, was smarter and more gutsy than the industry. The 938 pound structural weight was less than 10% of the airplane's gross! The distance record was actually doubled! In these high tech days, when do you hear of a world or Olympic record being doubled?

Voyager flew 26,358.6 miles. It had a nominal transcontinental reserve, indeed much more if flown precisely in August when the weather is friendly. When it's not, as in December when the flight was actually made, the crew was in for an adventure thriller to end them all!

If you'd like a copy of **Voyager, The World Flight**, with all the real facts and insights, you can get a copy identical to that in the National Archives for $12.95. Personally autographed by Dick and Jeana, it's $20.00. That's not a sales pitch. Profits go to Dick and Jeana, who worked so long and so hard, six years, to actually do "mission impossible." It's a great historical record to have. Copies are available from: Jack Norris, Technical Director, Voyager Mission Control, 11613 Seminole Circle, Northridge, CA 91326.