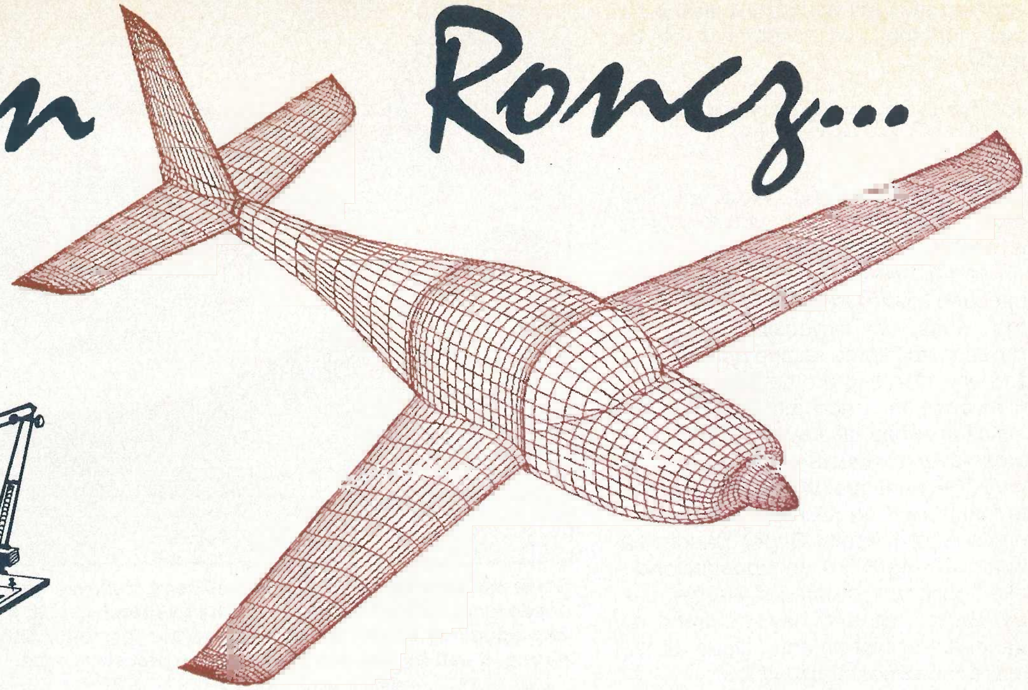
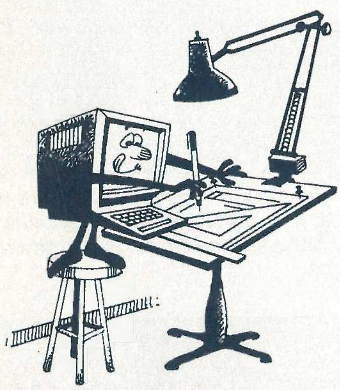
John Roncz...





A computer study of John Roncz's homebuilt.

DLR VERSION 9
X = 14.00E + 06 Y = 14.00E + 06 Z = 14.00E + 06 ITER = 1

Sizing Your Wings

by JOHN G. RONCZ, EAA 1132811
15450 Hunting Ridge Tr.
Granger, IN 46530-9093

Your homebuilt's wings are obviously the most important piece of your airplane. While you can design an aircraft without an engine, you can't have one without wings unless you have at least a pound of thrust for every pound of weight, in which case you'd have a rocket.

Your choice of wing designs will have two major impacts on the performance of your homebuilt: the first is the stall speed, which will of course also govern your takeoff and landing speeds. The second is the power-off rate of descent. I intend to dwell on that last point a lot. To date I have logged a bit under 1800 hours of flying time, and in that time I have had two engine failures. The first was precipitated by the delamination of a bearing surface on a rod end. The plane went in for a routine oil change and the mechanics found a lot of metal in the oil filter. I was very lucky that this failure was discovered on the ground!

The second time I was not so lucky. Returning from Ohio State University late one night, the crankcase split from top to bottom, leaving a thick film of oil all over the windshield so I couldn't see anything after it quit - precisely at half-past midnight. I made it to an airport, due partly to the fact that I had turned towards the airport immediately upon seeing the oil pressure dropping, and due in larger part to the fact that the airplane I was flying, a Rockwell 112A, had excellent power-off gliding ability. This experience taught me that single engine planes must be designed for power-off flight. Careful maintenance and oil analyses done every 25 hours at oil change time didn't prevent my two engine failures, and nothing you can do is going to change your luck, either.

While a wing is the source of the lift that makes flight possible, it is also the source of several kinds of drag. Since we have to push its many square feet of surface area through the skies, we pay a price in skin friction drag. Next, since the wing is producing lift, we pay an extra fee for this work, which is called induced drag - this is the drag created by the work of creating lift. The wing joins a fuselage somewhere, disrupting the smooth flow of air along the fuselage, and changing the pressure on the sides of the fuselage, creating interference drag. Finally, we tend to assault the pristine wing shapes by sawing holes in them for ailerons and flaps, and garbage like inspection covers, landing lights and wingtip lights. We pay a price for this desecration also.

There are some things we can do with the wing to minimize the price Nature charges us for her gift of lift. To get rid of skin friction drag, we can select laminar airfoil shapes. These have lower drag per square foot of wing area. We can make the wing smaller, making the drag smaller by trading it for higher approach and landing speeds. We can also try using high-lift devices so that we can have a smaller wing while maintaining our low landing speed. We can try sealing the flap and aileron gaps, though this may not always be a good idea. We can make our covers and seams smoother.

To lower the price we pay for induced drag, only one thing works: you must have more wing span. Induced drag is directly related to the amount of work the wing is doing, and in cruise is not very high. The induced drag dominates in the climb condition, however, when the wing is working harder.

To lower the interference drag, you can fillet the intersection, which is a bandaid measure. The real fix is to design the wing root airfoil and fuselage so that their pressure distributions do not adversely affect one another. However, this method needs complicated 3-dimensional analysis, which is beyond the capability of homebuilders.

Max Munk, who by the way taught EAA's own R. T. Jones, discovered that to minimize the induced drag of wings, the lift must be distributed spanwise in a semi-elliptical shape. This gives the optimum span loading. The Spitfire's elliptical planform is one way of doing this. In practice, however, it is difficult to get very far from an elliptical loading on a wing. A rectangular wing has almost a perfect span loading, for example. So the first assumption we're going to make is that our wing will be loaded semi-elliptically. From geometry, we know that the area of an ellipse is

area = pi * a * b

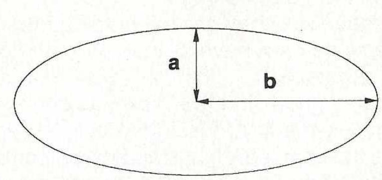


FIG. 1

where **a** is half the height, and **b** is half the width of the ellipse. For a wing, **a** represents the lift at Butt Line 0.0, the centerline of the wing, and **b** represents the semispan, or the span of one wing. In this case we count only half the area of the ellipse. Thus the lift produced by a properly loaded wing would be

lift = lift at BL 0 * semispan * pi / 2.

However, making another assumption, that the lift itself can be represented by the lift coefficient C_L, we can further simply things as follows:

average C_L = C_l at BL 0 * pl/4.

area = Cl at BL0 * semispan * pl / 2

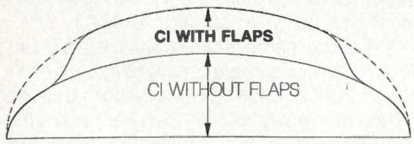
average CL = pi * Cl at BL0 / 4

FIG. 2

The issue here is that of two dimensions versus three. If we build a wind tunnel model to span the walls of the tunnel, no wingtip vortices can form, and the lift coefficient will be the same from wall to wall (neglecting boundary layers formed on the walls). The *local* lift coefficient, C_l (lower case **l**) will be the same everywhere. This is two-dimensional flow. You can get the same results by building your plane with an infinite wingspan. But it's hard to find a T-hangar to park it in.

However, if we build a model of a wing and put it in the wind tunnel, wingtip vortices will form in the tunnel, and for a properly loaded wing the highest lift will be at the centerline of the wing. The spanwise flow caused by the wingtip vortices makes the lift vanish at the wingtips, and makes the lift coefficients smaller as we come closer to the tips. This is three-dimensional flow, which fits nicely in a T-hangar. The *average* lift coefficient produced by the wing, C_L (upper case **L**) is therefore smaller than the C_l at Butt Line 0. Since π is a little bigger than 3, theory says that the average C_L of a wing will be a bit over 3/4 of the C_l at the centerline of the wing.

If you use flaps, you get less than pi/4 times the lift at the centerline because the flaps don't go all the way to the wingtips. Nor should they. At the wingtip itself, the lift will be zero. You can use leading edge slats and triple-slotted flaps, and the lift at the tips will still be zero. Since you can't fool Mother Nature, there is little point to carrying flaps all the way out to the tips. Then you'd have to use spoilers for roll control, since you won't have space for ailerons. The complexity and weight will not come close to being worth the little bit of lift that full span flaps offer you.



FOR FLAP = 65% OF SPAN
LOST LIFT = 7.2%

FIG. 3

My opinion is that flaps ought to cover 65%-70% of the span of one wing. In this case, the spanwise lift distribution will look like figure 3. Notice how the lift blends smoothly

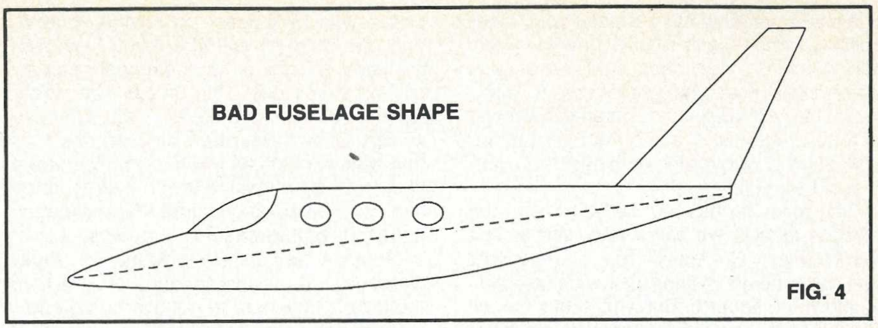


FIG. 4

back to the unflapped value at the flap tips. I counted, and the lift was 7% less than having full span flaps. We will use this knowledge to size our wing and determine its incidence on the fuselage.

But, you ask, on my airplane the wing is buried inside the fuselage, so how can you have lift at Butt Line 0 as you say? Well, the answer to this is that the pressure drop on the upper surface of the wing carries onto the fuselage sides, or the top for a high-winged plane, and makes the fuselage produce about the same lift as the wing buried inside it would have made. However, to get this fuselage lift you should avoid fuselages shaped like that in figure 4. The dotted line shows the effective camber line for this shape, and it looks very much like a flat plate at negative angle of attack. Therefore, this fuselage might well make negative lift, and would have a bad impact on the span loading, the induced drag of the plane, and the interference drag.

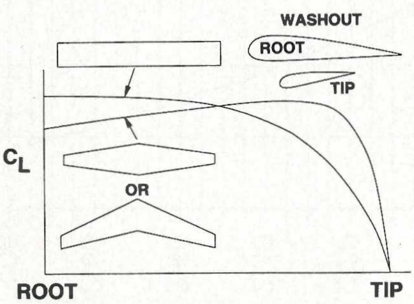


FIG. 5

While on the subject of spanwise lift distributions, we should pause long enough to consider wing shapes other than rectangular or elliptical. Figure 5 shows that for a rectangular wing, the lift coefficient is highest at the root, and falls off towards the tip. This will guarantee that the root will stall first, since the area of the wing with the highest lift coefficient stalls first. A root stall gives the airplane gentle stalling behavior. If you taper the wing severely, or if you sweep the wing back, then the highest lift coefficient occurs not at the root, but closer to the tip. This means the ailerons could stall first, leaving you with no way to control the rolloff tendency caused by the stall. This is not good! The fix for this is to incorporate washout, which means lowering the incidence of the wing tip airfoil with respect to the root airfoil incidence. This helps to protect the tips, although for large sweep angles such as are used on jets, not even this will cure the problem. Several of the reference books I gave you last time show how to calculate the spanwise lift coefficients for tapered and swept wings. The best that I've seen is in Peery's book on **Aircraft Structures**. If you plan to have a moderate taper ratio (tip ~ 60% of the root chord), use a washout of 1-1/2 degrees, and this will put you in the ballpark.

You're going to pick your wing size now, based upon the stalling speed you pick. I'd suggest that you consider this question from a different viewpoint: how much energy will your plane have when it smashes into something at half-past midnight with oil all over your windshield? All moving bodies have energy due to their motion. The energy is equal to one-half its mass times its speed squared. Remember that speed is measured in feet per second. So before you raise the stall speed by only 10%, be aware that the energy you will have to dispose of in a crash will go up by 21%.

The FAA came down from Mount Sinai with *61 KNOTS* written on the stone tablets. Thou shalt not certify a single-engine plane if the stall speed is any higher. I think this is an intelligent law, and one that you ought to respect, even though the fine print on the stone tablets allows homebuilders to violate this commandment. For my own homebuilt, I set the limit at 55 knots, because I'd like to fly into some short fields occasionally. While those 6 knots don't sound like much, it will take an additional 23% more lift coefficient to achieve! If you're into STOL planes, like my friend Fred Keller, and you want to stall at 30.5 knots, your wing would have to produce four times the lift coefficient than it needs for 61 knots! (Fred still owes me a beer.)

But now a brief message from our sponsor. . . .

The Acme Flap Company

TYPES OF FLAPS

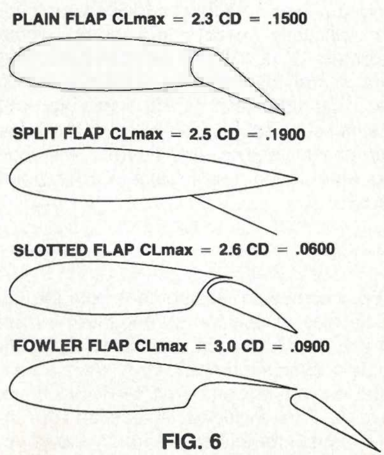


FIG. 6

We at Acme Flap have an offer you homebuilders simply can't refuse. Imagine yourself taking off from short fields at speeds which would have your present plane falling out of the sky! Imagine a romantic weekend at a fly-in resort with a short grass strip! Imagine all this with a wing no bigger than your present wing!

Yes, folks, all this can be yours with the modern miracle we call a **flap**. We at The Acme Flap Company are the world's foremost makers of flaps. Our wide selection is shown on figure 6. But wait, that's not all! Because you're an EAA member we have also included figure 7 at no extra cost!

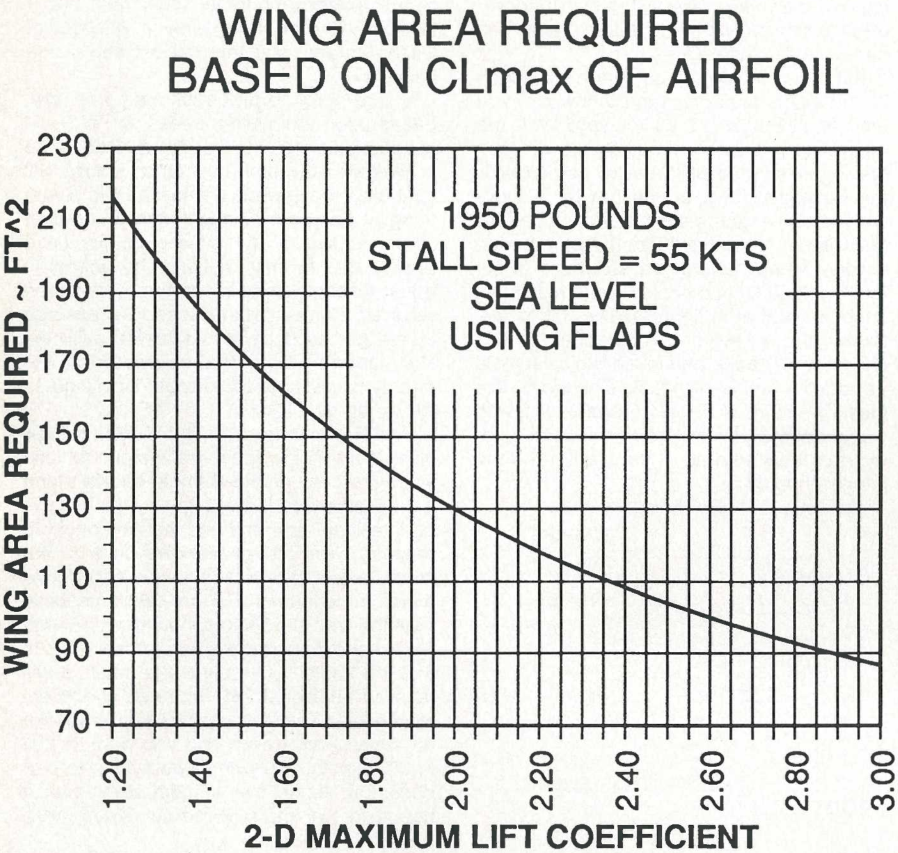


FIG. 7

Figure 7 shows you exactly how much wing area an Acme flap can save you! If you are currently using an airfoil whose maximum C_L is 1.5, you can **cut your wing area in half** by choosing an Acme Fowler Flap, and **still land at the same speed**!!! Yes, folks, it really works! So pick the Acme Flap of your choice, and figure 7 will show you how much you'll save. Order yours today!!!

Your homework assignment from the last article was to use the spreadsheet I wrote for you, and using the maximum lift coefficients I suggested, pick your wing area. I assume you've done that by now. If you haven't, I've included a section on the spreadsheet for this article which allows you to size your wing based on Acme's figure 6. The maximum lift coefficient you'll get with the various kinds of flaps depends a lot on the airfoil you use. Thin airfoils with pointy little noses will not do as well as those shown. On the other hand the last one I did that was wind tunnel tested demonstrated a maximum C_L of over 3.0 with just a slotted flap. So the values on figure 6 are averages for a 15% or thicker airfoil. A good source of information on flaps is found in **Fluid Dynamic Lift** by Hoerner and Borst. I'll give the details on where to get this at the end.

I am not going to preach at you about selecting airfoils, because I am hardly objective on this subject. I consider airfoils to be another design tool, tailoring them to have a happy marriage with the fuselage, and fretting over the aileron control forces and flap performance. I spend a lot of time working with separated flow, designing the stalling behavior specifically for stability and control reasons, trying mightily to predict and control the post-stall behavior of the plane. This is typical of the state of the art, but it is time consuming and difficult. My current passion in low-speed designs centers around laminar flow airfoils with positive pitching moments and high maximum lift. This is the approach I used on my own homebuilt. One advantage I'm looking for is that I can trim the airplane with almost no tail lift required. Cambered airfoils generally have negative pitching moments, which means that the wing is trying to make the airplane dive. This diving tendency is countered by producing negative lift on the tail. High pitching moments make it tough to get nice aileron forces, extract a penalty in trim drag, and make a bad marriage with the fuselage.

The pitching moment coefficients are published for all the airfoils, using the symbol C_M. C_M is the amount of moment, in foot-pounds, produced by a one foot square wing at a dynamic pressure of one pound per square foot. What you want to compare is the pitching moment around the quarter-chord point on the airfoil when the airfoil is producing zero lift, because the center of lift is located near the 1/4 chord point. A moment is simply a force times a distance. If you hold a five-pound hammer two feet from your armpit, you will have ten foot-pounds of torque or moment at your armpit.

To see how this works, assume that you have 90 square feet of wing, the average chord is 3 feet, and your plane is going 200 miles per hour at sea level. Further assume that the pitching moment of the wing is -.050. In this case, the dynamic pressure **q** is

.5 * .002377 * (200 * 1.467)^2 = 102.31

pounds per square foot. This was calculated using half the air density rho times the speed (in feet per second) squared. The pitching moment produced by this wing is then

102.31 * 90 * -.05 * 3 = -1381.18 foot-pounds.

This was calculated by multiplying the dynamic pressure by the wing area, then by the pitching moment, then by the average chord. If the center of lift of your tail is ten feet from the center of lift of your wing, then the tail would have to produce

-1381.18 / 10 = -138.12 pounds of lift

to counter the pitching moment of the wing. The negative sign means that the tail would have to make negative lift, which means it would lift down. Since the wing can't tell negative lift from weight, it also means that the wing has to carry another 138 pounds of phantom weight. A pitching moment of only -.050 is only moderate. Some newer airfoils have pitching moments of -.15 or even more. If you pick an airfoil with a pitching moment of -.15, then our sample tail would have to produce 414 pounds of negative lift just to counter the pitching moment. Of course, the tail would also have to produce more negative lift to trim the airplane. The equation we used above shows that the moments are a product of the wing average chord. Therefore, a short wing with a wide chord will have more moments than a long wing with a short chord. Since the dynamic pressure is a product of the speed squared, high speed planes will have much higher pitching moments to trim out than slower airplanes. The torsion these moments produce in the wing itself must also be taken out structurally.

Therefore some people passionately believe in zero pitching moment airfoils, like the NACA 23012. I don't like that airfoil because it has very nasty stalling behavior and only average drag. But the pitching moment issue I do believe has merit. I have recently advised some homebuilders to look at helicopter rotor blade airfoils, which also must control the pitching moments carefully. There are excellent sections available for helicopter rotor blades which would make fine wing airfoil sections. Other than that broad outline, I'll leave the choice of which airfoil you want to use up to you. The book *Theory of Wing*

Sections gives you many choices. It also gives you a lot of information on flap and aileron design. You can't design an airplane without it, so go order the book!

(Editor's Note: **Theory of Wing Sections** is available from EAA Headquarters. Cost is $10.95 plus $2.40 S/H. Call 800/843-3612 (in WI 800/236-4800) for your copy.)

Once you know your wing area, and the type of flap (if any) that you plan to use, the next question is to determine the wing span. To help you, I've written a spreadsheet that I think you'll find very useful. The objective is for you to get a feel for the effect of wing span on gliding performance. This is expressed in two ways. First, if you want to glide the furthest distance, you must fly at your best lift/drag ratio, which generally occurs at a relatively low speed. It was this requirement that kept Dick Rutan and Jeana Yeager cooped up in the Voyager for so long. Using your speed for best range, you've hopefully glided to the vicinity of an airport. Now your goal changes; you want to minimize your sink rate so that you can fly the approach. This is the speed for best endurance. The spreadsheet will calculate these for you.

Unfortunately, one of the things the equations need to know is the equivalent flat plate drag area of your airplane. What this means is that we are going to think of your airplane as a barn door being pushed through the sky. We need to find the size of the barn door, in square feet, that would have the same drag as your airplane. The way I do this, and I think it's the best way, is to start by adding up all the wetted area of your airplane. If you held the airplane by its tail, and dunked it into a (large) swimming pool, every square foot that got wet is wetted area. That means you have to count both the top **and** the bottom of the wings, for example. For the fuselage, you divide it into say, fifteen even strips, and you estimate the distance around the fuselage at each of the fifteen Fuselage Stations. From your drawing you know the height and width of the fuselage at each location. If the fuselage were a box, you would add the height to the width, then multiply by two to get the perimeter. If the fuselage was a circle, you would add the height to the width, divide by two, then multiply by pi to get the circumference. In practice most fuselage cross sections are somewhere in between a box and a circle, so pick a number in between depending upon how square your fuselage is at that location. Now add up all 15 perimeters, and divide by 15 to get the average. Now multiply by the fuselage length. Make sure that every number you just used was measured all in feet or all in inches, because they have to be the same. If you used inches for everything, now divide by 144 and you'll have the wetted area of your fuselage.

For wings and tails, I'll give you a shortcut. For a typical airfoil that is 12% thick, the wetted area is 2.042 times the wing area. For an airfoil that is 18% thick, the wetted area is 2.078 times the wing area. Obviously, if the airfoil had zero thickness, the wetted area would be exactly twice the wing area (one top + one bottom). For wing area or tail area, count only the wing area outside the fuselage, then multiply that area times one of the factors shown above based on airfoil thickness. Yes I know that we haven't sized the tails yet. So use 25% of the wetted area of the wing for this, and that will put you in the ballpark for now. Add the wing and tail wetted area to the fuselage wetted area and don't forget the prop spinner as well! You can compare the wetted area of your plane to these:

- VariEze 247.5
- Quickie 190.5
- Solitaire 297.3
- Long-EZ 325.0
- Catbird 398.8
- VariViggen 458.2
- Swift 460.8
- Defiant 517.8
- Voyager 1337.7
- Pond Racer 478.0
- Piaggio Avanti 1238.1
- Wheeler Express 487.0
- Glasair II 329.1
- Cirrus 565.5
- Glasair III 360.6
- Questair Venture 280.0
- Lancair 320 325.0
- Beech Bonanza 668.0
- Cessna 172 675.0
- Cherokee, 4-place 601.0
- Beech Musketeer 601.0
- Piper Malibu 730.0

Some of these may not be perfectly accurate, since they are based on 3-view drawings. Also the fixed gear airplanes in this list do not include the wetted area of the landing gear. You can use 25 square feet of wetted area for a fixed tricycle gear. This should help you compare your plane to others. Mine comes out to 412 square feet. The point of this exercise is that once you know the wetted area of your plane, you can easily find its equivalent flat plate drag area.

You do this by picking a drag value for each square foot of wetted area, then multiplying by the number of square feet you've got. The lowest drag value I've seen on any airplane I've worked on is .0037 per square foot, which is for the Triumph business jet designed by Burt Rutan, for which I did all the flying surfaces. A lot of factory made metal planes come out at between .0060 and .0065 per square foot. Most of the composite homebuilts are coming in at around .0050 per square foot. By the way, .0050 is pronounced "fifty drag counts", since .0001 is one drag count. I want you to sound professional, since you're now an airplane designer. If you're doing a metal plane with some round rivets, etc., use 65 drag counts. If you're doing a very clean plane out of plastic, with laminar airfoils and a lot of attention to drag, use 45 drag counts. The production Starship, before they glued rubber deicing boots on, had 44 drag counts per square foot. I used .0048 for my homebuilt, but I sure hope it turns out better than that, considering all the blood and sweat that's gone into it so far!

So examine your conscience, pick a target drag value, and multiply the drag counts per square foot by the wetted area of your plane. The answer you get is the size of your equivalent barn door, measured in square feet. Once you know this number, you can calculate all kinds of interesting things, including the top speed of your homebuilt!

Next time we'll look at special problems with my homebuilt's wing and how I analyzed them, and we'll determine the angle of incidence for the wing and size our tails. Meanwhile, since you may have wondered what my homebuilt looks like, I'll show you an earlier version which has the tails on. The current version is nicer, but I'm still playing with it and haven't put the tails on yet.

* * * *

REFERENCES

- Hoerner and Borst, *Fluid-Dynamic Lift*. Published by Mrs. Liselotte Hoerner, 1975
- Hoerner Fluid Dynamics, P.O. Box 342, Brick Town, New Jersey 08723.
- Abbott and Von Doenhoff, *Theory of Wing Sections*, Dover Publications, Inc., New York.

* * * *

MAKING THE SPREADSHEET

The spreadsheet for this article is very ambitious. It will do three things for you. The first section will tell you the top speed of your airplane, the speed for best range, the maximum lift-to-drag ratio, the speed for minimum sink rate, and what that sink rate is. This will let you trade between speed and the glide ratio of a brick.

The second part of the spreadsheet lets you calculate the equivalent flat plate drag area based upon published performance numbers for any airplane of your choice. If you know or can estimate the wetted area of that design, it will give you the drag counts per square foot of wetted area. Using this, you may be able to discover whether the performance specs for the homebuilt design of your choice are fact or fiction.

The last part of the spreadsheet lets you calculate the wing area required to stall at the speed you choose, using several kinds of flaps.

Then you can place your order with The Acme Flap Company.

Set the column width to 19 for column A, and to 17 for column D.

Type the labels as shown into their respective cell addresses:

A1: 'SPREADSHEET #2
A2: 'FROM SPORT AVIATION
A3: '1/90 JGR
A5: 'To calculate best range speed, minimum descent speed and top speed
A6: \=
A7: 'SPAN (FT):
A8: 'ALTITUDE (FT):
A9: 'WETTED AREA (FT^2):
A10: 'DRAG PER FT^2:
A12: 'RHO:
A13: 'BEST L/D (MPH):
A14: 'BEST L/D:
A15: 'MIN DESCENT (MPH):
A16: 'DESCENT (FT/MIN):
A17: 'MAX SPEED (MPH):
A19: 'To Calculate Drag Area Using Published Performance Data

A20: \=
A21: 'HORSEPOWER:
A22: 'ALTITUDE:
A24: 'TOP SPEED (MPH):
A25: 'F (TOTAL):
A26: 'WETTED AREA:
A27: 'CD,F:
A29: 'To Calculate Wing Area Required
Based on Type of Flap Used
A30: \=
A31: 'GROSS WEIGHT:
A32: 'ALTITUDE:
A33: 'STALL SPEED (MPH):
A35: 'Type of Flaps Used
A36: 'NONE
A37: 'PLAIN
A38: 'SPLIT
A39: 'SLOTTED
A40: 'FOWLER
B35: "CLmax
C13: ^=
C15: ^=
C17: ^=
C24: '=
C33: '=
D7: 'WEIGHT (LBS):
D8: 'E:
D9: 'HORSEPOWER:
D10: 'PROP EFF'Y:
D12: 'FLAT PLATE AREA:
D21: 'PROP EFF'Y:
D22: 'RHO:
D31: 'RHO:
D32: 'Q:
D35: 'Wing Area Required (ft^2)
E13: 'KNOTS
E15: 'KNOTS
E17: 'KNOTS
E24: 'KNOTS
E33: 'knots

Again, an apostrophe ' tells Lotus 1-2-3 to left-justify the title in the column. The ^ symbol tells 1-2-3 to center the title in the column, and the quotation mark " tells 1-2-3 to right-justify the title in the column. The \= in cells A6 and elsewhere is shorthand telling 1-2-3 to fill the column with = = ='s.

Now carefully type the formulas into their proper cells. After you finish each formula, you may be greeted with an ERR message in the cell. This doesn't mean that you typed anything in wrong. It means that you haven't yet typed in the numbers that these formulas are trying to crunch. The error displays will go away as you fill in the blanks later on.

B12: @IF(B8<36089,(1-.0000068753*
B8)^4.2561*.00237689,
.2971*@EXP(-(B8-36089)/20806.7)*
.00237689)
B13: .72425*@SQRT(E7/(B12*B7*@SQRT
(E8*E12)))
B14: .886227*B7*@SQRT(E8/E12)
B15: .5502*@SQRT(E7/(B12*B7*@SQRT
(E8*E12)))
B16: 1.051651*60/E8*@SQRT(E12*E7*
@SQRT(E8/E12)/(B7^3*B12))
B17: (348.642*E10*E9/(B12*E12))
^.3333333
B25: 348.642*B21*E21/(E22*B24^3)
B27: +B25/B26
D13: +B13/1.152
D15: +B15/1.152
D17: +B17/1.152
D24: +B24/1.152
D33: +B33/1.152
D36: +B31/(E32*B36*@PI/4)
D37: +B31/(E32*B37*@PI/4*.93)
D38: +B31/(E32*B38*@PI/4*.93)
D39: +B31/(E32*B39*@PI/4*.93)
D40: +B31/(E32*B40*@PI/4*.93)
E12: +B9*B10
E22: @IF(B22<36089,(1-.0000068753*
B22)^4.2561*.00237689,
.2971*@EXP(-(B22-36089)/20806.7)*
.00237689)
E31: @IF(B32<36089,(1-.0000068753*
B32)^4.2561*.00237689,
.2971*@EXP(-(B32-36089)/20806.7)*
.00237689)
E32: 0.5*E31*(B33*1.467)^2

As a reminder, when the first character in a formula is a letter, Lotus 1-2-3 will presume that you are typing in a title rather than a formula. In order to inform Lotus that this is a cell address, 1-2-3 uses a plus sign + to indicate that this is a cell address rather than a title. For users of Excel, replace the plus signs + with equal signs =, which does the same thing in Excel. By the way, if you couldn't get 1-2-3 to accept the title listed for cell A3, the reason is that this title begins with a number rather than a letter. You needed to preceed the number by an apostrophe in order to let Lotus know that this is a title rather than a formula.

To verify that the spreadsheet is working properly, type in the values shown in their proper cells:

B7: 30.694
B8: 0
B9: 415
B10: .0048
B21: 160
B22: 0
B24: 241
B26: 329.1
B31: 1950
B32: 0
B33: 55*1.152
B36: 1.5
B37: 2.3
B38: 2.5
B39: 2.6
B40: 3
E7: 1950
E8: .7
E9: 180
E10: .85
E21: .85

Your spreadsheet should look exactly like the sample shown. Since I chose to make the inputs in miles per hour rather than knots, you may be annoyed if you think in knots. If you look at cell B33, however, you'll find an easy way around this. To convert knots to miles-per-hour, you multiply by 1.152. Remember that the computer can do this for you, so in B33 I typed 55 times 1.152, and Lotus did the conversion for me. You can type a formula into any cell that expects a simple number. If you want to check my homebuilt's cruise speed at 7500 feet and 75% power, for example, you would enter 7500 into cell B8, and you could type 180*.75 into cell E9 and let the spreadsheet calculate 75% of your 180 horsepower for you. This is why I love computers.

USING THE SPREADSHEET

The example in the sample spreadsheet is for my homebuilt. The only items not talked about in the article are propeller efficiency and **e**. For a constant speed propeller in cruise, use 85% efficiency, or .85, and this will be very close. For a fixed pitch cruise prop, use .80 and for a climb prop use .77. The other parameter is **e**, which is the span efficiency. Remember that if your wing produces a perfect semi-elliptical span loading, the efficiency is 100%, or 1.0. However, the fuselage and propeller slipstream will mess up even an elliptical wing, and your wing is probably not elliptical anyway. For light airplanes, the span efficiency is usually not much better than 70%, or .70. What this means is that a 30 foot wing will have the same performance as a 21 foot wing, if its span efficiency is 70%!

The sample spreadsheet shows that my plane should have a minimum sink rate of 522 feet per minute. You'll notice that the engine power makes no difference, since these calculations are done for a zero power condition. However, this number does not take into account the drag of a windmilling propeller. I estimate this to be 1 square foot. To do this, I go to cell B9 and type 415*2.992/1.992, letting Lotus do the work of figuring out how much additional wetted area would change the drag from 1.992 square feet to 2.992 square feet. Now my minimum sink rate increases to 577 feet per minute. This is only 55 feet per minute more than it was before! Yet we know that a windmilling prop would do a lot more harm than this. If I go back to cell B9 and type 415*4.992/1.992, which means that I am adding 3 square feet of drag area to the baseline, the rate of descent increases to 656 feet per minute.

The reason that the flat plate drag doesn't do that much harm to the sink rate is that as I add drag, the speed I need to obtain the minimum sink rate is going down. It was 72 knots for the first case, and is now down to 57 knots. Of course I can't fly the plane at 57 knots, since I'd need full flaps and would be only a couple of knots above the stall speed at that. At low speeds the drag is determined more by the induced drag than by all other kinds of drag, since the wing is working very hard at low speeds, and is charging us a lot for all that work. Restore the original 415 square feet of drag area in cell B9, and then change **e** to .5 in cell E8. Now our minimum sink rate really jumps. Also, the speed we need to fly to get this minimum also jumps. This tells us that a windmilling prop actually does its damage by changing the span efficiency more than by its added drag area. I suspect that the span efficiency can be as low as 30% with a windmilling prop.

Use this part of the spreadsheet to imagine yourself at half-past midnight with no engine and oil obscuring your vision, and carefully look at the speeds you'll have to fly to get the maximum range and minimum sink. If you want some fun, try modelling the Voyager. Span is 110.8 feet, weight on takeoff was 9694, wetted area is 1337.7 square feet, power (total) was 230, use .6 for span efficiency (extremely long skinny wings have bad **e**'s), .0050 for drag and .72 for prop efficiency (low speed prop efficiency isn't very good). You can see that for best range you'd fly at 85 knots, that the plane could glide 29.4 feet forward for every foot it dropped (best L/D), and that minimum sink is only 258 feet/minute, although at a speed well below the stall speed at that weight.

SPREADSHEET #2
FROM SPORT AVIATION
1/90 JGR

To calculate best range speed, minimum descent speed and top speed

SPAN (FT):	30.694		WEIGHT (LBS):	1950
ALTITUDE (FT):	0		E:	0.7
WETTED AREA (FT^2):	415		HORSEPOWER:	180
DRAG PER FT^2:	0.0048		PROP EFF'Y:	0.85
RHO:	0.002376		FLAT PLATE AREA:	1.992
BEST L/D (MPH):	108.9626	=	94.585638699 KNOTS	
BEST L/D:	16.12511			
MIN DESCENT (MPH):	82.77701	=	71.855047859 KNOTS	
DESCENT (FT/MIN):	521.7401			
MAX SPEED (MPH):	224.1768	=	194.597919 KNOTS	

To calculate drag area using published performance data

HORSEPOWER:	160		PROP EFF'Y:	0.85
ALTITUDE:	0		RHO:	0.002376
TOP SPEED (MPH):	241	=	209.20138889 KNOTS	
F (TOTAL):	1.425142			
WETTED AREA:	329.1			
CD,F:	0.004330			

To calculate wing area required based on type of flap used

GROSS WEIGHT:	1950		RHO:	0.002376
ALTITUDE:	0		Q:	10.26761
STALL SPEED (MPH):	63.36	=	55 knots	

Type of flaps used	CLmax	Wing area required (ft^2)
NONE	1.5	161.20697114
PLAIN	2.3	113.04836686
SPLIT	2.5	104.004497512
SLOTTED	2.6	100.00432453
FOWLER	3	86.670414593

Now reduce the weight to 3000 pounds. The best range speed drops to only 47 knots, and the minimum sink rate is only 143 feet per minute! Voyager didn't fly this slow because these equations assume that the parasite drag stays the same at all angles of attack, and in reality the flow begins to separate from the wings, and the intersection drag and other drags are going up at high angles of attack. If you can't fly at the speed required to achieve the minimum rate of sink, then you will sink faster. If you can't fly at the speed for maximum range, you won't fly as far.

You can also use this part of the spreadsheet to answer the question of how much faster the airplane would go with a bigger or smaller engine, or with a more efficient prop.

The second part of the spreadsheet allows you to have fun with published performance numbers for designs you may lust after. The sample shows the figures published for the Glasair II RG with 160 horsepower. Using the wetted area from the chart in the article as an educated guess, this airplane would have 43 drag counts per square foot of wetted area, which is very low indeed. You can take the numbers you get here and put them into the first section of the spreadsheet to play with different engines, etc., and to look at sink rates. If you don't know the wetted area, don't despair. You can either guess using the chart above, or you can type in cell B9 the drag area from cell B25 and divide by the drag per square foot that you consider reasonable, and which you enter into cell B10. For the Glasair example, cell B25 says the flat plate drag is 1.425142 square feet. If I assume a drag coefficient of .0047 per square foot, I'd type 1.425142/.0047 into cell B9, and the spreadsheet will tell you that the wetted area in this case would have to be 303.2217 square feet. Let's continue this exercise by filling in the other blanks at the top for the Glasair: span is 23. 3, horsepower is 160, prop efficiency is .85, **e** is .7, weight is 1800 pounds. The minimum rate of descent turns out to be 697 feet per minute at 99 miles per hour. Now for fun type in 180 horsepower, and note that the top speed changes to 251 miles per hour for this engine. Glasair publishes 256 miles per hour for the 180 horsepower version, so either they have cleaned up the 180 horsepower version some over the 160 horsepower version, or they measured wrong. So get out the 3-views and published performance for any plane you want, and discover for yourself whether the marketing department is trying to fool Mother Nature!

The last part of the spreadsheet lets you calculate your wing area using several kinds of flaps. Just enter the gross weight, altitude and your desired landing speed, and you'll get a list of wing areas with different kinds of flaps. The maximum lift coefficients I put in for different kinds of flaps are a general guideline. I have also adjusted the equations to account for the fact that the flaps aren't full span. Feel free to type in different numbers for $C_L$max to see what effect this has on your wing area.

NOTES ON THE EQUATIONS USED IN THE SPREADSHEETS

I am embarrased to tell you how many hours it took me to derive the equations used in this spreadsheet. I haven't done that much calculus and algebra in ages, but I did it myself because I enjoy doing things like this, and because it became a game to see how simple I could make each equation.

The only assumption that I made was that the drag polar was parabolic, which is generally a valid assumption. The equation for the speed to fly in miles per hour to obtain the best L/D turned out to be:

.72425 * (span / (rho * span * (**e** * flat plate area) ^ .5))) ^ .5

The equation to determine the best lift-to-drag ratio was:

.886227 * span * (**e** / flat plate area) ^ .5

The equation to predict the speed to fly in miles per hour to obtain the minimum sink rate is:

.5502 * (weight / (rho * span * (**e** * flat plate area) ^ .5)) ^ .5

The minimum sink rate possible is expressed in feet per minute by:

63.09906 / **e** * (flat plate area * weight * (**e** / flat plate area) ^ .5 / (span ^3 * rho)) ^ .5

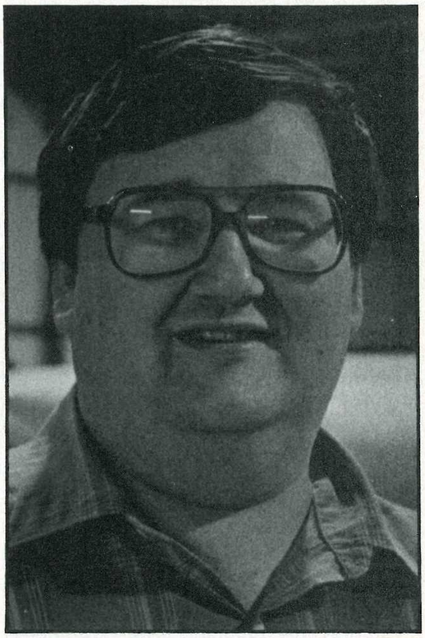
The top speed calculation neglects induced drag, which should be small at high speeds anyway. The equation I used is:

(348.642 * horsepower * prop eff'y / (rho * flat plate area)) ^ (1/3) and the answer is in miles per hour.

For the purists among you, I also calculated what the equivalent flat plate drag due to the induced drag would be:

F (induced) = .274909 / **e** * (weight / (span * rho * speed in mph ^2)) ^2

However, I ended up not using it in the spreadsheet, since it was already complicated enough. You can put this into your own spreadsheet if you want to.



JOHN RONCZ
(See July 1985 issue of S.A. for the full story on John.)