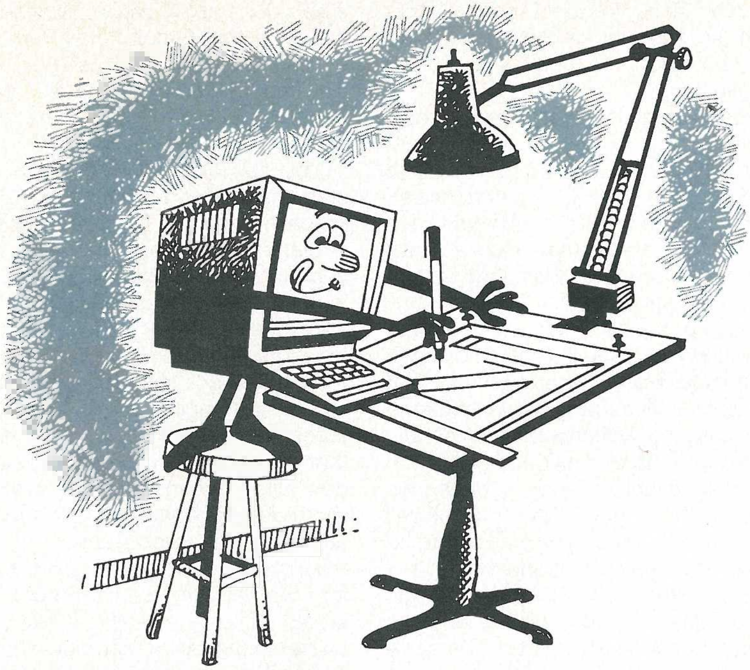

John Roncz...

Designing Your Homebuilt

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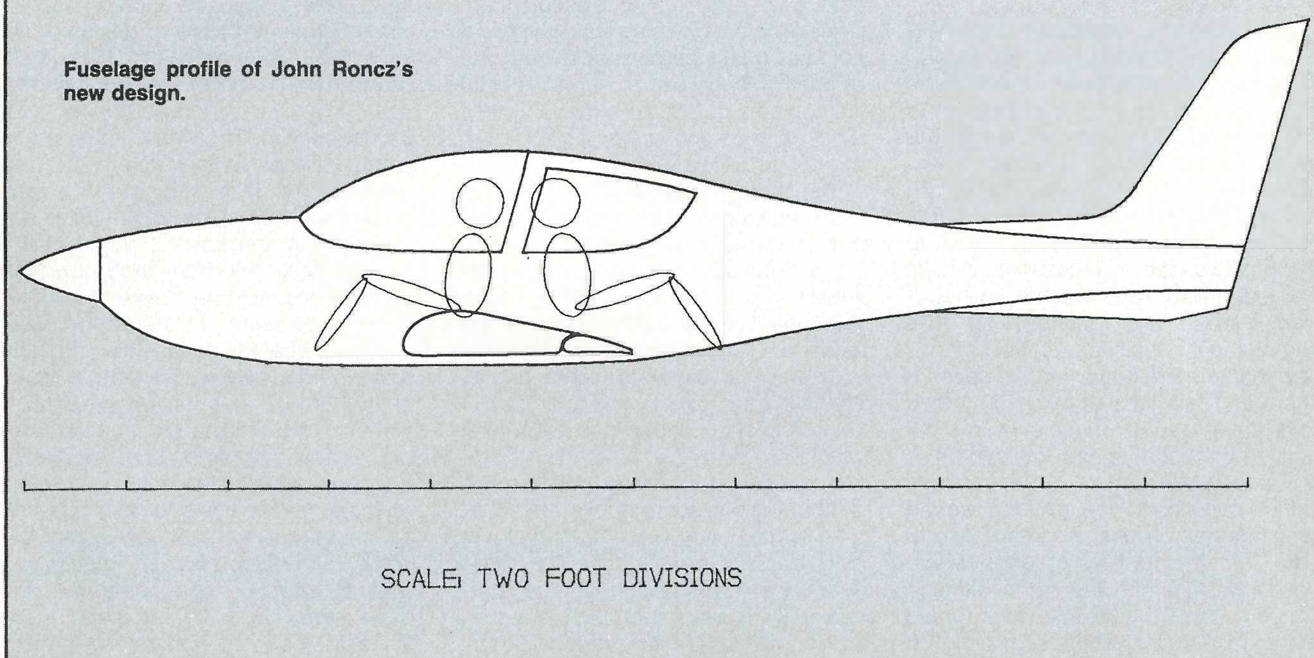
At Oshkosh in 1989 I gave a forum in the EAA Design College called "Designing Your Homebuilt." So many people have asked for copies of the viewgraphs and formulas from that talk that I decided to write it up for **Sport Aviation**. This also gives me the opportunity of showing you how to use simple spreadsheet programs to help you design your airplane.

Last summer I ran across this statement, which deeply moved me: "I believe that the American homebuilder has a moral duty to develop new and original aircraft designs because he has everything necessary at his immediate command. We are living in the wealthiest country in the world . . . The technical information is practically free. The NACA and the U. S. Government Printing Office send free at your request, or at cost price, the best manuals and reports. Everyone has a garage and can buy tools at a price that cannot be matched in other countries. The average American citizen can devote his weekends to playing golf, or any other hobby he cares to pursue. In other words, he is a 'time millionaire'. All these conditions represent the background that should produce more and better aircraft designs." The EAA published this statement by famed EAA member Ladislao Pazmany in 1957. Except for the fact that the NACA is now called NASA, the statement is more true



Fuselage profile of John Roncz's new design.

today than it was in 1957.

There is even a better reason today: the availability of cheap yet powerful computers. The IBM AT I'm writing this on is more powerful than the UNIVAC 1107 I first tried programming in high school. My Compaq 386/20's are about as powerful as the IBM 370 mainframe I used in college. Most people know someone who has a computer, and almost everyone who has a computer has a spreadsheet program, like Lotus 1-2-3 or Microsoft Excel. With these you need not be a programmer to use the computer to help you do the tedious calculations that aircraft design may require. I'll try and show you how to set up the formulas and plots for your spreadsheet program during this article. That's how I generated the plots I used in the EAA Design College forums. To help you make your spreadsheets, I'm going to put all the formulas in these articles into Lotus 1-2-3 language. I understand that Excel and other spreadsheets can understand the Lotus formulas.

While I've been privileged to work on 17 aircraft designs which have already flown, with a few more still in the womb, I have always flown factory-made airplanes. I owned three different airplanes from 1975 to 1987, when I reluctantly sold my Beech Duchess because the cost of insuring it and operating it was becoming oppressive. A couple of years of standing in line at airports, waiting for lost luggage, and being stranded by cancelled or late flights has convinced me that I need an airplane. No factory-made airplane currently available satisfies my desire for fast, comfortable yet affordable transportation. So I decided to bite the bullet and design my own. I will be using my own design as a test case throughout these articles.

Designing your homebuilt starts by a realistic look at what your needs are. Most pilots are attracted to speed in the same way as the Japanese beetles in my backyard hurl themselves into the bags under the synthetic sex-pheromone disks. While I was an airplane owner, I made dozens of flights from my home base in South Bend to Wichita, Kansas - a distance of 569 nautical miles (655 statute miles). I flight-planned my Duchess for 160 knots, and it usually did a little better. I flew that trip with headwinds of up to 70 knots and tailwinds of up to 50 knots. This gave me an appreciation of how much difference speed makes on a rather lengthy flight.

Figure A shows the effect of speed on my trip to Wichita. It's interesting to note that if you flew at an average speed of 142 knots, the trip would take you 4 hours. To save one hour, you'd have to fly at an average speed of 190 knots. This would cut your flight to 3 hours. Now, to save yet another hour, you'd have to go 280 knots. What I learned from my frequent trips was that ten knots one way or the other saved or lost me about ten minutes on a 3-1/2 hour flight.

Speed is even less important on shorter trips. On a more typical flight from South Bend to Columbus, Ohio, which is 188 nautical miles (217 statute miles), going from 160 to 200 knots would save me less than 15 minutes. Occasionally I've spent more time than that waiting for my turn for take-off.

While I prefer twins, my wallet prefers singles. My homebuilt is going to have one engine. My own decision was that if my homebuilt could give me the same 160 knots as my Duchess, I'd be happy. A more important consideration for me was the reliability and maintenance costs for the engine. On my Rockwell 112A, the 200 HP engine was by far the biggest maintenance headache. On my Duchess, which had 180 hp Lycomings, I never spent a penny on the engines beyond normal maintenance. Therefore I decided to design the airplane around the 180 horse Lycoming engine, because of its ready availability, low maintenance requirements and low operating costs. Since the engine is going to be the heaviest single item in the airplane, you have to start by choosing your engine, and getting its weight and the weight of all its accessories, including the propeller, its governor and prop extension, if you're going to use one.

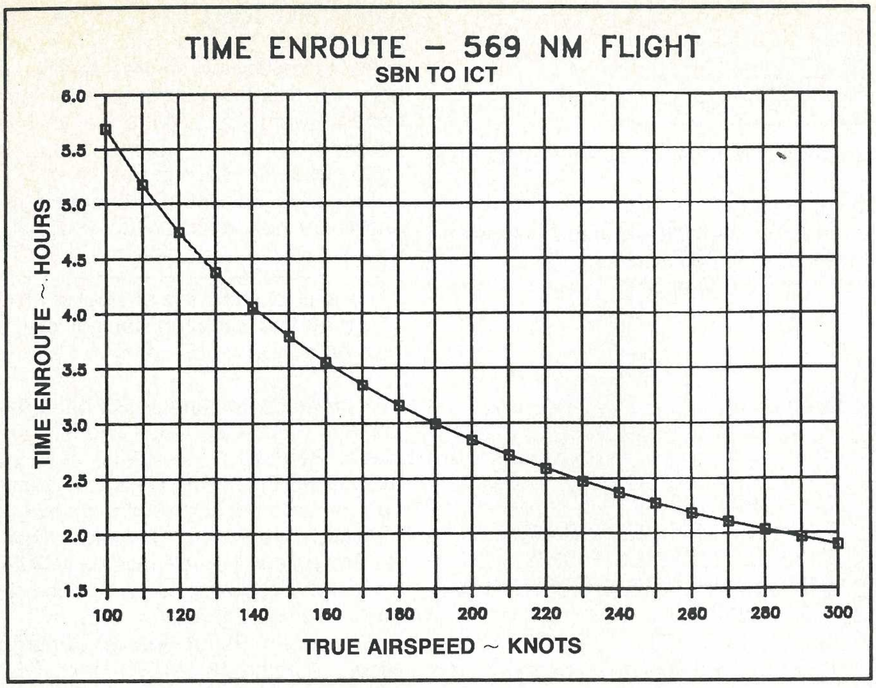
I originally wanted a 2-seat airplane. But we found that with a modest stretch, we could add 2 aft-facing seats behind the front 2 without making the airplane too much bigger. Since both my partners have kids, they wanted to be able to have more than 2 people in the plane. The big question was whether or not the airplane could handle the center of gravity range with 4 seats. The aft-facing seats do put the centers of gravity of each person closer together, so I agreed to try this.

The owner's handbooks for any factory-made airplane are a wealth of information on what things weigh. Look in the weight and balance section, and you'll find a long list of equipment along with their weights and locations for that airplane. You'll need to start making your list of radios, steps, lights, and everything else you're going to stuff in your airplane, and what each item weighs.

You also cannot design your airplane without buying some books and doing a lot of studying. I'll recommend some at the end of this article. There are many details that I won't talk about that these books will cover. After you buy your books, don't be intimidated by them. Yes, the formulas have things like Greek letters in them, and maybe some calculus that might scare you. However, if you don't know that an upside-down y (λ) is the Greek letter lambda, it doesn't mean you can't use the formula. Call it an upside-down y if you want. I'll try to show you which formulas you need and how to use them.

You can also go to the airport and start measuring the distance from the propeller flange to the firewall for airplanes which use the kind of engine you plan to use. Peek inside the cowlings of airplanes at your local maintenance shop, and while you're at it measure the engine height and width, etc. You're going to draw a scale version of the engine, so get all the measurements now. If a factory can stuff all that junk in there, you should be able to do it also. Now measure the height and width of the firewall. Doing this for a few airplanes will quickly show you about how much room you're going to need for the engine compartment. Most stores that sell drafting supplies also sell templates for scaled-down humans. Try and buy a one-tenth scale human. This is a convenient size for making drawings. While you're there buy lots of drawing paper. I like mine with ten squares to the inch.

At this point in your design what you have is a packaging problem. Your mission is to get all the people, radios, instruments, and propulsive devices inside some fuselage-shaped container. This is the time when you need to decide what kind of configuration you're going to build. I'll limit myself to "conventional" configurations, meaning one wing in front and one tail in back. While canards and three-surface airplanes can be used to solve some packaging and performance problems, you would need professional help and very sophisticated computer tools to design these kinds of airplanes. That puts them beyond the reach of most homebuilders. My own homebuilt is old-fashioned. Start drawing a side-view of your airplane, beginning with the propeller flange. Then draw in the firewall at the correct fuselage station (FS). You can draw in the correct height of the firewall, since you measured how high and low it should be above the center of the prop flange at the airport. Now use your scaled human template and draw in your people. Be sure to leave enough room to push on the rudder pedals without hitting the firewall. Draw the instrument panel and everything else you can think of. Make a list of everything you drew and estimate the horizontal and vertical position for the center of gravity of each item, along with its weight. Then go ahead and draw a top view in the same way, starting with the prop flange and firewall width.



In airplane lofting, distance down the fuselage is called the fuselage station or FS. Distance vertically is called the waterline or WL. Distance along the wing span measured from the centerline of the fuselage is called a buttline or BL (I've also heard the term Wing Station). You can measure the FS and WL from any arbitrary position, as long as you indicate where the reference lines are on your drawing. You could decide that the prop flange or firewall was FS 0.0, for example. If the firewall is FS 0.0, then the prop flange would be at a negative FS location. It's best to make FS 0.0 someplace ahead of the airplane. That way you won't be confused with negative numbers when you calculate your weight and balance. You could make the ground be WL 0.0, or the bottom of the fuselage, or anyplace else that becomes an easy point to measure from vertically. Wherever you put WL 0.0, anything below that will be a negative number, and anything above it will be a positive number.

At this time, the wing and tails can be sketched in place roughly, using your sense of judgment. Later we will size them more scientifically.

WING DESIGN

There are three considerations you will be using to size your wings. The first is that wing area will control your landing speed. The second is that wing span will determine your climb and glide performance. The third is that the area and span will determine your power-off rate of descent. The best way to get a handle on these tradeoffs is to use a computer spreadsheet, although you can certainly do the calculations by hand. All discussions of wings center about the term C_L, or lift coefficient. The C_L is the amount of lift, in pounds, produced by one square foot of wing at a dynamic pressure of one pound per square foot. Dynamic pressure is what you feel when you put your hand outside your car window when driving. It is defined as one half the density of the fluid (air) times the speed squared. In formulas the dynamic pressure is represented by the letter "q". The symbol for density is the Greek letter rho, which looks like a curvy small "P" (ρ). This is why aerodynamicists make the big bucks. It is important to remember that V, which stands for speed, is always measured in feet per second. The reason for this is that density is measured for a cubic foot, and the wing area is measured in square feet, so the speed has to be in feet to be consistent. In aerodynamics, one second is one unit of time. To get speed in feet per second, multiply miles-per-hour by 1.467, or multiply knots by 1.689. The density of air at sea level on a "standard" day is .002377 slugs per cubic foot of air. Julia Child has published several good recipes for cooking your slugs once you have finished using them in your calculations.

Let's give a formal definition:

Lift=.5*rho*V^2*S*C_L

The symbol "S" represents wing area in square feet. In level, unaccelerated flight, the wing lift has to equal the weight of the airplane. Therefore,

S = weight/(.5*rho*V^2*C_L)

or C_L = weight/(.5*rho*V^2*S)

or V = @SQRT(weight/(.5*rho*S*C_L))

What this means is that if you cut the speed in half, the wing will have to produce four times the C_L, because the C_L varies with the square of the speed. Note that @SQRT is the Lotus function which calculates square roots.

The key relationship for sizing your wing is the formula which solves for S (wing area) when given the speed and C_L. For this case, the speed is your stall speed, and the C_L is the maximum lift coefficient your wing can make before stalling. For now, use a C_{Lmax} of 1.22 for a wing with no flaps, 1.8 for a wing with simple flaps (hinge inside the flap), 2.0 for a wing with a slotted flap (hinge below the flap), and 2.36 for a wing with a Fowler flap (flap on tracks).

The spreadsheet for this article allows you to play with the tradeoffs required to size your wing. Right now, you don't have a gross weight for your airplane, so instead use the weights of other airplanes which are similar to yours. At the top of the spreadsheet, enter the altitude, the stalling speed you want (in knots) and the gross weight. The spreadsheet then calculates the density rho for that altitude and shows the speed in miles-per-hour and feet-per-second.

The spreadsheet allows you to select three "KNOWNs", and then solves for the appropriate unknowns. Using the altitude and speed entered at the top, you can specify C_L then solve for wing area, you can specify wing area and solve for C_L required, or you can specify C_L and wing area for the altitude you picked, and solve for your stall speed. Now type in the numbers suggested above under "KNOWN" for C_L; the spreadsheet will tell you how many square feet of wing you need for the altitude and speed you entered at the top. Now fly to Denver by typing 5000 for altitude, and note that the wing has to get bigger to maintain the same stall speed. Lower the stall speed by ten knots, and note how much wing area you have to add to achieve this. See how much wing area you would need to get the same stall speed with no flaps, and with all the varieties of flaps.

When you have a feel for this, go ahead and select a wing area by entering it under the word "KNOWN". Now you can select climb and cruise speeds at different altitudes, and develop a feel for how the C_L changes with different airspeeds and altitudes. Try setting a cruise speed at 7500 feet, then pretend you're turbocharged and change the altitude to 25,000 feet. See what happens to the C_L in that case.

The last option in the spreadsheet ignores the speed you entered at the top, and instead solves for speed based on the wing area and C_L you choose. Select an appropriate C_L from the list above, and select a wing area. The spreadsheet will tell you your stall speed in knots. Now change the altitude and see what happens to your stall speed. I want you to get a feel for how small reductions in landing speed require large increases in C_L.

The next article in this series will show you how to calculate your wing area.

Here is a short list of books which you may find useful in designing your own homebuilt.

- **Airplane Performance, Stability and Control**, Perkins, Courtland D. and Hage, Robert E. John Wiley & Sons, Inc., New York, 1949. (This is a classic book which most aero engineers own.)
- **Design for Flying**, Thurston, David B., McGraw-Hill Book Company, New York, 1978. (Shows how design choices affects flying qualities.)
- **Fundamentals of Aircraft Design**, Nicolai, Leland M., METS, Inc., 6520 Kingsland Court, San Jose, CA 95120, 1984. (Emphasis on military fighters, but contains all the equations needed for a general aviation design as well.)
- **Airplane Aerodynamics**, Dommasch, Daniel O., Sherby, Sydney S., and Connolly, Thomas Pitman Publishing Corporation, New York, 1967. (This is my favorite college textbook on aerodynamics. Emphasis is on our kinds of airplanes. Excellent.)
- **Light Airplane Design**, Pazmany, Ladislao, Pazmany Aircraft Corp., Box 80051, San Diego, CA 92138. (Good introduction to aircraft sizing and performance.)
- **A Practical Guide to Airplane Performance and Design**, Crawford, Donald R., Crawford Aviation, Box 1262, Torrance CA 90505. (Lets you calculate performance based on design choices. Aimed at the beginner.)
- **Airplane Aerodynamics and Performance**, Lan, Chuan-Tau Edward, and Roskam, Jan, Roskam Aviation and Engineering Corp., Route 4, Box 274, Ottawa, Kansas 66067. (College textbook. Covers the material well.)
- **Airplane Design**, Crawford, Donald R., address shown above. (A collection of 15 articles from **Kitplanes** magazine. Contains BASIC programs which calculate dynamic stability, a small vortex-lattice program, and other good tools for doing performance analysis. Terse, but has many pictures. The guided tour of the Greek alphabet and all the math will scare most people.)
- **Aircraft Structures**, Peery, David J., McGraw-Hill Book Company, New York, 1950. (The bible of aircraft structures. Chapter 9 on spanwise air-load distribution is done better than in any aerodynamics book I've seen. Lots of math, but there's no other way.)

MAKING THE SPREADSHEET FOR THIS ARTICLE

To make the spreadsheet which demonstrates the relationships between lift, density, wing area and C_L:

First set the column width to 16 for columns A and D.

The following shows the cell address, followed by the titles you need to type in each cell. Cell address B13, for example, refers to the cell at column B and row 13. For titles, the character ' tells 1-2-3 to left-justify the title, while ^ tells Lotus to center the title in the cell.

A1: 'Spreadsheet for calculating basic lift parameters
A2: 'from Sport Aviation
A3: 'JGR 11-89
A5: 'H(altitude):
A6: 'V(knots):
A7: 'W(weight):
A9: ^KNOWN
A10: 'CL(lift coef):
A12: ^ KNOWN
A13: 'S(wing area):
A15: ^ KNOWN
A16: 'S(wing area):
A17: 'CL(lift coef):
D5: 'rho(density)
D6: 'V(ft/sec)
D7: 'V(mph)
D9: 'SOLVE FOR
D10: 'S(wing area)
D12: 'SOLVE FOR
D13: 'CL(lift coef)
D15: 'SOLVE FOR
D16: 'V(knots)

Now type the formulas carefully in their proper cells:

E5: @IF(B5<36089,(1-.000006875347*B5)^4.2561*.00237689,.2971*@EXP(-(B5-36089)/20806.7)*.00237689)
E6: +B6*1.689
E7: +B6*1.152
E10: +B7/(.5*E5*E6^2*B10)
E13: +B7/(.5*E5*E6^2*B13)
E16: @SQRT(B7/(.5*E5*B16*B17))/1.689

Hints on conversion to other non 1-2-3 spreadsheets: The @IF in cell E5, which calculates rho, works like this:

@IF (test, do if test is true, do if test is false)
@SQRT calculates square roots
@EXP calculates anti-logs

In cell E6, for example, +B6 refers to the contents of cell B6. In Excell, I believe that the + is replaced by =.

To test your spreadsheet, enter the following values into their proper cells:

B5: 0
B6: 55
B7: 1850
B10: 1.5
B13: 100
B16: 100
B17: 1.803881

Your spreadsheet should then be identical to the one shown below.

Spreadsheet for calculating basic lift parameters from Sport Aviation JGR 11-89

H (altitude):	0	rho (density)	0.002376
V (knots):	55	V (ft/sec)	92.895
W (weight):	1850	V (mph)	63.36
KNOWN		SOLVE FOR	
CL (lift coef):	1.5	S (wing area)	120.2587
KNOWN		SOLVE FOR	
S (wing area):	100	CL (lift coef)	1.803881
KNOWN		SOLVE FOR	
S (wing area):	100	V (knots)	55.00000
CL (lift coef):	1.803881		